GLASILO SLOVENSKIH TEKSTILCEV • SLOVENE JOURNAL FOR TEXTILE AND CLOTHING TECHNOLOGY, DESIGN AND MARKETING

tekstilec

1/2022 • vol. 65 • 1–80
ISSN 0351-3386 (tiskano/printed)
ISSN 2350 - 3696 (elektronsko/online)
UDK 677 + 687 (05)

Univerza *v Ljubljani*
Naravoslovnotehniška fakulteta

http://www.tekstilec.si

tekstılec (ISSN: 0351-3386 tiskano, 2350-3696 elektronsko) je znanstvena revija, ki podaja temeljne in aplikativne znanstvene informacije v fizikalni, kemijski in tehnološki znanosti, vezani na tekstilno in oblačilno tehnologijo, oblikovanje in trženje tekstilij in oblačil. V prilogah so v slovenskem jeziku objavljeni strokovni članki in prispevki o novostih v tekstilni tehnologiji iz Slovenije in sveta, prispevki s področja oblikovanja tekstilij in oblačil, informacije o raziskovalnih projektih ipd.

tekstılec *(ISSN: 0351-3386 printed, 2350-3696 online) the scientific journal gives fundamental and applied scientific information in the physical, chemical and engineering sciences related to the textile and clothing industry, design and marketing. In the appendices written in Slovene language, are published technical and short articles about the textile-technology novelties from Slovenia and the world, articles on textile and clothing design, information about research projects etc.*

Dosegljivo na svetovnem spletu/*Available Online at*
www.tekstilec.si

Crossref

Tekstilec je indeksiran v naslednjih bazah/*Tekstilec is indexed in*
Emerging Sources Citation Index – ESCI (by Clarivate Analytics)
(2020: Journal Citation Indicator, JCI: 0.35)
Leiden University's Center for Science & Technology Studies
(2020: SNIP 0.705)
SCOPUS/Elsevier (2020: Q3, SJR 0.270, Cite Score 1.6, H Index 11)
Ei Compendex
DOAJ
WTI Frankfurt/TEMA® Technology and Management/
TOGA® Textile Database
World Textiles/EBSCO Information Services
Textile Technology Complete/EBSCO Information Services
Textile Technology Index/EBSCO Information Services
Chemical Abstracts/ACS
ULRICHWEB – global serials directory
LIBRARY OF THE TECHNICAL UNIVERSITY OF LODZ
dLIB
SICRIS: 1A3 (Z, A', A1/2); Scopus (d)

tekstilec

Ustanovitelja / *Founded by*
- Zveza inženirjev in tehnikov tekstilcev Slovenije / *Association of Slovene Textile Engineers and Technicians*
- Gospodarska zbornica Slovenije – Združenje za tekstilno, oblačilno in usnjarsko predelovalno industrijo / *Chamber of Commerce and Industry of Slovenia – Textiles, Clothing and Leather Processing Association*

Revijo sofinancirajo / *Journal is Financially Supported*
- Univerza v Ljubljani, Naravoslovnotehniška fakulteta / *University of Ljubljana, Faculty of Natural Sciences and Engineering*
- Univerza v Mariboru, Fakulteta za strojništvo / *University of Maribor, Faculty for Mechanical Engineering*
- Javna agencija za raziskovalno dejavnost Republike Slovenije / *Slovenian Research Agency*

Izdajatelj / *Publisher*
Univerza v Ljubljani, Naravoslovnotehniška fakulteta / *University of Ljubljana, Faculty of Natural Sciences and Engineering*

Sponzor / *Sponsor*
Predilnica Litija, d. o. o.

Revija Tekstilec izhaja štirikrat letno / *Journal Tekstilec appears quarterly*

Revija je pri Ministrstvu za kulturo vpisana v razvid medijev pod številko 583. Letna naročnina za člane Društev inženirjev in tehnikov tekstilcev je vključena v članarino.
Letna naročnina za posameznike 38 €
za študente 22 €
za mala podjetja 90 € za velika podjetja 180 €
za tujino 110 €

Cena posamezne številke 10 €

Na podlagi Zakona o davku na dodano vrednost sodi revija Tekstilec med proizvode, od katerih se obračunava DDV po stopnji 5 %.

Transakcijski račun 01100–6030708186
Bank Account No. SI56 01100–6030708186
Nova Ljubljanska banka d. d.,
Trg Republike 2, SI–1000 Ljubljana,
Slovenija, SWIFT Code: LJBA SI 2X.

Naslov uredništva / *Editorial Office Address*
Uredništvo Tekstilec, Snežniška 5, SI–1000 Ljubljana
Tel./*Tel.*: + 386 1 200 32 00, +386 1 200 32 24
Faks/*Fax*: + 386 1 200 32 70
E–pošta/*E–mail*: tekstilec@ntf.uni–lj.si
Spletni naslov / *Internet page:* http://www.tekstilec.si

Lektor za slovenščino / *Slovenian Language Editor* Milojka Mansoor
Lektor za angleščino / *English Language Editor* Chris Bishop, Barbara Luštek-Preskar

Oblikovanje platnice / *Design of the Cover* Tanja Nuša Kočevar
Oblikovanje / *Design* Miha Golob
Oblikovanje spletnih strani / *Website* Design Jure Ahtik

Tisk / *Printed by* PRIMITUS, d. o. o.

tekstilec VOLUME 65 • TEKSTILEC 1 2022 ISSN 0351-3386 (tiskano/printed)
UDK 677 + 687 (05)

SCIENTIFIC ARTICLES/ *Znanstveni članki*

Dibyendu Bikash Datta, Partha Seal, Sanjana Mariam George, Senjuti Roy
National Institute of Fashion Technology (Ministry of Textiles, Govt. of India), Kolkata 700106, India

Factors Influencing Women's Buying Decisions while Shopping for Lingerie Products Online

Dejavniki, ki vplivajo na odločitve žensk pri spletnem nakupovanju spodnjega perila

Original scientific article/*Izvirni znanstveni članek*
Received/*Prispelo* 6-2021 • Accepted/*Sprejeto* 11-2021

Corresponding author/*Korespondenčna avtorica:*
Dibyendu Bikash Datta, Assoc Prof
E-mail: dbdatta@gmail.com
Phone: +91-9433327019
ORCID ID: 0000-0003-0028-5571

Abstract

One reason driving lingerie sales in India is growing e-commerce and a rising demand for premium brands. With improved technologies, many lingerie producers are using delicate fabrics and intricate lace trimmings for lingerie of different styles to enhance lingerie demand in the country. Rising demand for lingerie sets, a growing middle-class population, and an increasing number of financially independent women are all driving this development. Many professional opportunities for women, and their access to round-the-clock internet services, have enabled them to gain trust, feel inspired, and be praised for their ability to decide. Their familiarity with technological advances like internet access via smart phones has enabled the Indian lingerie industry to shift their focus from an earlier marketing strategy of "touch and feel," being available only in retail stores, to going online and taking the additional risk of advertising their product line on e-commerce platforms. This study found factors that influence women's buying decisions while shopping online for lingerie products. Questionnaires were distributed to Indian women consumers to gauge their online buying intentions and multiple linear regressions were used as a statistical method to evaluate the formed hypotheses. The study revealed that convenience of shopping, variety of brands, quality of products, online discounts, delivery services and secure online payment have a positive impact on the buying decisions of Indian women regarding lingerie products. The research findings will serve as a baseline for understanding the major aspects that influence retailers' online lingerie buying decisions.
Keywords: buying decisions, online shopping, lingerie, quality, variety, discounts

Izvleček

Eden od razlogov za spodbujanje prodaje spodnjega perila v Indiji je naraščanje števila e-trgovin in povpraševanja po vrhunskih blagovnih znamkah. Napredne proizvodne tehnologije so izdelovalcem spodnjega perila omogočile uporabo občutljivih tkanin in zapletenih čipk za izdelavo perila različnih stilov, da bi povečali povpraševanje po spodnjem perilu v državi. Ta razvoj spodbujajo naraščajoče povpraševanje po kompletih spodnjega perila, rastoča populacija srednjega razreda in čedalje več finančno neodvisnih žensk. Številne poklicne priložnosti in dostop do 24-urnih spletnih storitev so ženskam omogočili, da so pridobile zaupanje, se počutile navdihnjene in bile pohvaljene za svojo sposobnost odločanja. Njihovo poznavanje tehnološkega napredka, kot je dostop do spleta s pametnimi telefoni, je indijski industriji spodnjega

perila omogočilo premik od marketinške strategije »dotika in občutka«, ki je izvedljiva samo v maloprodajnih trgovinah, k spletni prodaji in s tem prevzela dodatno tveganje pri oglaševanju svojih linij izdelkov na platformah e-trgovin. Ta študija je odkrila dejavnike, ki vplivajo na nakupne odločitve žensk med spletnim nakupovanjem izdelkov za spodnje perilo. Med indijske uporabnice so razdelili vprašalnike, da bi ocenili njihovo spletno nakupovalno namero kot statistično metodo, za oceno oblikovanih hipotez pa so bile uporabljene večkratne linearne regresije. Študija je pokazala, da ugodnost nakupovanja, raznolikost blagovnih znamk, kakovost izdelkov, spletni popusti, dostavne storitve in varno spletno plačilo pozitivno vplivajo na odločitve indijskih žensk za nakup perila. Ugotovitve iz raziskave bodo izhodišče za razumevanje glavnih vidikov, ki vplivajo na spletne odločitve prodajalcev o nakupu spodnjega perila.
Ključne besede: odločitev o nakupu, spletno nakupovanje, spodnje perilo, kakovost, raznolikost, popusti

1 Introduction

Women's lingerie is undergoing a renaissance. Lingerie shopping was traditionally not a pleasant experience for women, with discussions on the topic occurring in hushed tones. Offline lingerie shopping in India is often an inconvenience for women and men. Lingerie shopping is an intimate experience that needs privacy and freedom regardless of the factors such as the environment and people. Many consumers had unpleasant lingerie shopping experiences and are hesitant to buy in an offline store again. The reasons are understandable as lingerie shopping in India is generally tied to a social stigma, and talking about size and shape is still taboo. Although lingerie-related awkward moments persist, women have become more confident in experimenting and buying 'intimate' wear in recent years, and this trend can be attributed to online lingerie sites to a large extent, if not completely. Women no longer shy away from sharing their feelings in a category that is closet essential.

The Indian lingerie market is primarily driven by the rise in the adoption of western culture, growing urbanisation, a rise of disposable income, more women participating in sports and physical activities, a change in consumer preferences, deep expertise in lingerie design, presence in online space and social media impact. There has been exponential growth in recent years to meet the demand for fashionable, contemporary, and premium-quality lingerie. The segment has improved gradually with easy product availability in hypermarkets, supermarkets, multi-brand outlets, exclusive business outlets and online platforms. While physical stores ring in the bulk of sales, the unavailability of sizes, lack of privacy, and shortage of trained personnel have paved the way for online lingerie portals. Lingerie purchasing in India has progressed from small, packed stores staffed by untrained salespeople to enticing websites staffed by fitting specialists. Many Indian companies have reaped the benefits of e-commerce implementation and integration into their enterprises by shifting their marketing approach from brick and mortar locations to the Internet. The product descriptions for online products are extremely detailed, even including visual elements that contribute to understanding of the functionality. Some brands launch a series of infomercials to educate female consumers on different categories. In recent years, Skype and phone calls have become available for consultations on fitting-related issues. Women have now spoken up on issues that have been taboo for many years. Buying online enables the transaction to be kept private and delivered discreetly, providing online lingerie businesses with an advantage over traditional stores. In addition to privacy, other factors that drive lingerie retailing include discounts, the availability of foreign brands, a wide range of designs, and different size options ranging from slender to plus-size.

The Indian lingerie sector has been a fast-growing driver in the apparel industry and is currently experiencing its most exciting era, with a diverse consumer base which enables brands to experiment with designs, styles, cuts, and colours. What was originally a staple product with little innovation has developed into an impregnable market. Its tale of development and importance, particularly in the Internet world, has captivated and piqued the interest of investors like nothing else. Today, multiple lingerie brands compete fiercely in e-commerce. This has flared up the entire industry, which is populated by a diverse range of global, national, regional, and online players. The Indian lingerie market is projected to rise at a robust Compound Annual Growth Rate of 14 per cent, reaching EUR 3.69 billion in 2021 and EUR 7.1 billion in 2026, owing to the growing middle-class population, fashion, wellness, and media visibility, as well as more women

Table 1: Categories of the online lingerie retail sector

Online category	Major brands
Multi-category apparel	Amazon, Fashionara, Flipkart, Jabong, Myntra, Snapdeal (other best-selling clothing items is highlighted)
Private lingerie labels	Amante, Enamor, Lovable, PrettySecrets, (product aimed at brand-loyal customers)
Exclusive multi-brand online lingerie portals	The Darling Trap, Straps and Strings, Zivame (exclusive lingerie brands)

becoming financially independent. According to a Technopak survey, the lingerie category is currently worth EUR 2.95 billion and accounts for 8% of India's overall apparel industry. Luxurious, premium, mid-market, and mass-market are now the most popular categories in the Indian lingerie sector, with the mid-market category accounting for the most sales. Compared to the mid-market category, the premium and luxury sectors are rising at almost double the rate. While foreign brands such as Calvin Klein, La Senza, Victoria's Secret, and others are vying for a piece of the Indian industry, domestic brands are stepping up their game as well [1]. The current companies in the online lingerie retail sector in India can be categorised into three types.

Several lingerie brand advertisements incorporate experiential marketing, which is more effective than traditional commercials. These online educative steps and assistance reach out to more consumers and offer to pick the 'right fit' innerwear. The Enamor positioning 'Fabulous As I Am' is derived from the stance that women look forward to everything that life offers - from jobs and occasions to family time. Amante's latest campaign, positioning itself on 'Dare To Be', urges women to embrace different personalities, whether it be a serious executive by day or an enchantress by night. Online player Zivame's 'Fit For All' campaign is based on the idea that, much like Indian women, lingerie should be available in various sizes. It was created in response to consumer feedback that most women had difficulty finding lingerie in sizes other than the predefined "so-called popular sizes."

Technological advances in lingerie production aid the development of this industry, with an increasing number of factories using superior quality fabrics and carving enticing designs. Technical inputs extend the horizons from a basic necessity to designer wear, with a focus on style and comfort. In recent years, the e-commerce boom in the B2C sector has witnessed extensive growth, and the lingerie industry has stepped up its efforts to reach out to its customers through its online mode. Online availability of lingerie products has made women avoid embarrassment, buy in a private ambience, get a consultation if necessary and spend more time selecting what they want. As a result, male consumers are emerging as significant buyers of women's lingerie because of the privacy it offers. This brought the lingerie enterprises hope and confidence to revise their strategy since they recognised an opportunity that they wanted to build on. This study finds the correlation between various factors that influence women's buying decisions for online lingerie products and statistically validate the findings through the use of multivariate statistical tools. The objectives of the study are the following:

i). To determine the factors influencing the buying decisions of women across India concerning lingerie products during online purchase, and
ii). to establish and validate that the determining factors positively affect the buying decisions of women concerning online lingerie products.

The research provides useful insights into what women desire, helping different marketers to develop and adapt in response to the needs of female Indian consumers. The most satisfied customers usually have the intent to re-purchase if product performance meets their expectations. Thus, to influence customers and improve business performance, online retailers must clearly understand the factors that positively affect buying decisions. Several studies are available to categorise the various variables that influence online shopping. A few of them are extensively explored during the review of the literature.

1.1 Literature review

Several studies have been conducted to determine the factors that influence consumers' buying decisions for online shopping. A consumer must be happy with their first online shopping experience before buying more products and services online [2]. It is also stated that the service offered during the purchase is essential in convincing consumers to make repeat purchases online [3]. Consumer views and beliefs regarding comfort and protection concerns have a very significant effect on their decision to buy online [4]. Women, on the whole, have a good outlook about shopping for apparel online [5]. While women are aware of some disadvantages of online apparel shopping, these drawbacks do not deter them from doing so. The Internet user base is growing rapidly in India, and it is inspiring to see that the women's user base is also increasing rapidly [6]. Due to the Internet, Indian women have convenient access to information, enabling them to make smarter decisions in their everyday lives. Most youngsters (18–25 years old) are particularly interested in online shopping because they are familiar with the technology [7].

The simplicity with which products on a website can be navigated has a positive effect on online purchasing behaviour and purchasing decisions [8]. Security is another significant aspect that influences online shopping satisfaction. Security vulnerabilities during online shopping have also been reported in the literature. It was further discussed that the ability of an online portal to protect a customer's data fosters loyalty and improves satisfaction. According to previous research work [9], satisfaction with the information service of online retailers is expected to rise as the perception of security risks declines. A high level of protection affects the extent to which purchasing decisions are made.

The quality of product details on e-commerce websites is another important aspect that influences buying decisions. Consumer satisfaction in online shopping is influenced by accurate product and quality information. Online shoppers require websites to provide safe payment options and protect the privacy of their online communications [10]. According to Pappas et al. [11], information content, website architecture, product attributes, ease of purchases, online transaction security, payment, delivery, and consumer services were good predictors of online buying decisions. The same study states that a wide range of merchandise variety and a relatively low price would have a positive impact on buying decisions in the online shopping environment.

Convenience is the backbone of e-commerce, and it is one of the primary reasons that online shopping has grown in popularity in recent years. Shopping convenience can be defined as consumers' perceptions of the time and effort involved in buying products and services [12]. Shopping online offers the convenience of purchasing items when and where it suits you, via a payment method of choice, while also having the item delivered via a suitable method. Corbitt et al., argue that purchase-related information and the opportunity to compare alternative deals play an important role in the absence of sales personnel and the inability to view and try the product [13]. Research reports show that shopping convenience has surpassed price and selection and has become the number one reason consumers shop online [14].

Trust and security appeared to be interconnected, where the consumer needed a secure payment to trust the payment method. If there is insufficient trust in the online payment process, the purchase is likely to be cancelled. Choosing an appropriate secure payment system for online transactions creates a more trustworthy condition for the consumer [15]. A strong transaction security policy helps gain a shopper's trust to purchase online, without the worries of risks in the transaction [16]. Most consumers in the e-commerce world believe that big businesses are more trustworthy, which can influence their trust and online buying intentions [17]. Scholars stated that trust performs a critical role in e-commerce because of the limited face-to-face communication between retailers and consumers in the virtual world. Hence, the intention of consumers to shop online derives from their trust in their information security. However, scholars have argued that further external factors play a vital role in purchasing intentions [18].

Apart from trust, perceived quality was found as another critical component of online purchase intention. Perceived quality is defined as the quality of a consumer product or service that is based on its ability to satisfy stated or implied customer needs, which in turn affects a customer's buying decisions. Perceived quality is considered when consumers evaluate the quality of the product to choose which product suits them the most [19]. Customers are likely to visit an online shop with various and high-quality products. If the product quality meets the expectations, customers regard the online shop as useful and continue to visit it. Therefore, product-related characteristics can develop, sustain and improve customer satisfaction in online shopping. In an online purchase, a consumer cannot touch and feel the product; hence, quality perception plays a vital role in determining product perception and trust in the vendor [20].

The variety of products offered to consumers while shopping online is difficult to match by offline stores. Offline shoppers usually have to visit different stores to search for the products, whereas online shopping provides a wide variety of products on a single website. Product perception is also termed product value, which entails understanding a product in terms of price, product quality, and variety. Price is defined as the cost paid for an item by the consumer, and it should be comparable with prices available for the same product at alternative sources (online or offline). Product variety is the number of alternatives available to the customer when choosing a product. Product quality perception is the product's ability to satisfy the customer [21].

The most important factors influencing online purchase are convenience and attractive pricing [22]. The retailers can attract online bargain hunters with a visible selection, discounts, and special promotions (e.g. incentives and gifts). Consumers can easily compare prices from various suppliers, leading to utilitarian browsing for purchases [23]. As a marketing stimulus, price comprises positive and negative cues in predicting consumer behaviour. In the online context, consumers depend on price information, as the product is not available for examination before purchasing. Increasing the usability and perceived depth of online information can reduce price sensitivity [24].

The product delivery problem is prominent in an online retail environment and has a significant impact on purchasing decisions. Customer loyalty suffers when products arrive with a delay. In an online environment, timely and reliable delivery plays a critical role in meeting customer's expectations and satisfaction. Customers can switch easily between webpages with just a single click or even customers move toward conventional brick and mortar retailers because of late, unsafe, or undesirable product delivery. It can be concluded that a delivery service is a service organised by a supplier or a shop to take goods to customers. Several studies state that the delivery quality has a significant impact on purchasing decisions and accounts for a larger variation in online shopping satisfaction. In the scenario of an online shopping environment, reliable, safe, and timely delivery is a fundamental and integral aim of online buyers [25]. Customers buy products at home, and require a safe, reliable, and quick delivery of the desired product to their destination. The delivery service is the link in a supply chain that directly deals with customers, and is a driver of customer satisfaction [26].

While online shopping has several advantages over the traditional method, there are a few pitfalls of internet buying. In virtual shops, the consumer cannot see and check the product quality, as would be the case in a physical store. In fact, for the consumer, buying products on the Internet appears to be a more complex decision as it is more difficult to form an impression about whether the products on offer are appropriate. The second area of complexity concerns the mode of payment for the ordered products. Most of the consumers who are habituated to paying in cash at the checkout may find the electronic transfer and security checks unfamiliar and more complex [27].

Attracting, retaining, and satisfying female customers remains limited, despite the growth in the application of technology-based online retail services. A marketer often encounters a difficulty in understanding and managing the dynamics of female consumer behaviour. This requires a study of behavioural issues in online retail shopping in order to establish an online presence. While the number of female consumers buying online products in India continues to rise, the success of some e-retailers and the lack of such for others emphasise the need for research. What leads a female buyer to shop online has also evoked a lot of interest from both researchers and marketers. Thus, through an elaborate review of existing literature on buying decisions for online shopping, we determined that buying decisions depend on many factors. Some factors identified through the literature review have a significant influence on buying decisions and have been considered in this study. The factors identified are (i) convenience of shopping, (ii) variety of brands, (iii) quality of products, (iv) online discounts, (v) delivery services, (vi) secure online payment.

1.2 Hypothesis

Based on the literature review, the following hypotheses were developed for this study concerning buying decisions of Indian women for lingerie products:

H_1: Convenience of shopping influences buying decisions during online shopping.

H_2: Variety of brands influences buying decisions during online shopping.

H_3: Quality of product influences buying decisions during online shopping.
H_4: Online discounts influence buying decisions during online shopping.
H_5: Delivery services influence buying decisions during online shopping.
H_6: Secure online payment influences buying decisions during online shopping.

2 Methodology

A total of 150 questionnaires were circulated at random among female Indian consumers from diverse backgrounds to better understand what motivates them to buy online lingerie products. Their identities were kept anonymous to ensure that their reasoning and preferences are not criticised or differentiated, and that their confidentiality is maintained throughout. The non-probability convenience sampling [28] was used in this exploratory research study, as it is the most effective way to obtain basic information quickly and efficiently. Only responses from 120 female respondents over the age of 16 were received. In this study, the questionnaire comprises close-ended questions showing demographic and variable-related information for measuring online buying decisions. This was derived from a response range of strongly agree to disagree, on a five-point Likert Scale. The questionnaire was simple and easy to understand, so that the respondent would have no difficulty answering them. This comes under a correlational study that attempts to examine the statistical association between online buying decisions influenced by six independent variables identified as significant in buying decisions. The variables were the convenience of shopping, variety of brands, quality of products, online discounts, delivery services, and secure online payment. Secondary data sources include the previously published research papers, journals, authorised industry statistics, and some major websites, all of which contributed to data credibility. The validity of these responses was confirmed using the statistical tool of Multiple Regression Analysis. Cronbach's alpha coefficient was used to assess the internal consistency reliability of the data set [29].

3 Results and discussion

The survey was gender specific, and only women from various backgrounds were included. Most of the 120 participants were students (50 per cent) between the age group of 21 to 25 years. (38.3 per cent). There was no upper age limit for women who took part in this survey, and all respondents were over the age of 16. Table 2 shows the age group, education status, occupational status, and monthly income of all women respondents.

Table 2: Demographic data of women respondents

Demographics	Description	Frequency, N	Share (%)
Age group (years)	16–20	8	6.7
	21–25	46	38.3
	26–30	25	20.8
	31–35	17	14.2
	36–40	12	10.0
	40 or above	12	10.0
Education status	High School	9	7.5
	Graduate	63	52.5
	Postgraduate	38	31.7
	Doctorate	10	8.3
Occupational status	Student	60	50.0
	Employed	32	26.7
	Business	24	20.0
	Homemaker	4	3.3
Monthly income (EUR)	Below 1000	26	21.7
	1000–2000	14	11.7
	2001–3000	15	12.5
	3001–4000	22	18.3
	Over 4000	43	35.8

3.1 Reliability analysis

Table 3 shows the reliability coefficient (Cronbach's alpha) values for the variables under study. The Cronbach's alpha for all the proposed variables exceeds the minimum threshold value of 0.70 [30], with values ranging from (0.701) to (0.836), confirming that the data is statistically reliable and acceptable for further analysis.

Table 3: Reliability analysis of independent variables

Variables	Items	Cronbach's Alpha
Convenience of shopping	3	0.711
Variety of brands	5	0.836
Quality of products	5	0.733
Online discounts	2	0.753
Delivery services	2	0.789
Secure online payment	3	0.701

3.2 Multiple regression analysis

Tables 4a and 4b show the results of multiple regression analysis. The independent variables had multicollinearity if the tolerance value is below 0.1 and the value of Variance Inflation Factor (VIF) spans from 1.096 to 1.690, all of which are less than 5, showing no multicollinearity among the six independent variables [31].

Table 4a: Model summary

Model	R	R^2	Adjusted R^2	Std. Error of the estimate
1	0.857	0.734	0.720	0.59766

Table 4b: Regression analysis–ANOVA

Model	Sum of squares	df	Mean square	F	Sig.
Regression	32.684	6	5.447	15.250	0.000
Residual	72.51	203	0.357		
Total	105.194	209			

Predictors: (Constant), convenience of shopping, variety of brands, quality of products, online discounts, delivery services, secure online payment

All six independent variables have p-values less than the alpha value of 0.05 showing that all six independent variables, i.e., convenience of shopping, variety of brands, quality of products, online discounts, delivery services, and secure online payment are positively related to buying decisions of Indian women regarding lingerie products. The study supports both previously proposed hypotheses. The following multiple regression equation was formed using the coefficient table (Table 4c):

Buying decisions = 1.163 + 0.248 (convenience of shopping) + 0.124 (variety of brands) + 0.059 (quality of products) + 0.022 (online discounts) + 0.178 (delivery service) + 0.132 (secure online payment).

The intensity among variables is explained by the data of standardised coefficients. The variables are ranked in order of intensity:

- convenience of shopping (0.360)
- secure online payment (0.171)
- variety of brands (0.151)
- quality of products (0.093)
- delivery services (0.084)
- online discounts (0.026).

Table 4c: Regression analysis - coefficients

Model	Unstandardised coefficients		Standardised coefficients	t	Sig.	Collinearity statistics	
	B	Std. error	β			Tolerance	VIF
(Constant)	1.163	0.252		4.615	0.000		
Convenience of shopping	0.248	0.047	0.360	5.247	0.000	0.720	1.388
Variety of brands	0.124	0.055	0.151	2.256	0.002	0.760	1.316
Quality of products	0.059	0.046	0.093	1.286	0.000	0.645	1.551
Online discounts	0.022	0.052	0.026	0.420	0.005	0.912	1.096
Delivery services	0.178	0.043	0.084	1.262	0.000	0.771	1.297
Secure online payment	0.132	0.058	0.171	2.257	0.025	0.592	1.690

Dependent variable: Buying decisions

Based on the values of the standardised coefficients above, it can be inferred that convenience of shopping is the most important variable that influences Indian women's online purchasing decisions of lingerie items positively, while secure online payment is the second most influential variable. The remaining factors follow the first two.

According to Table 4a, the coefficient of determination (R^2) is 0.734. This shows that a 73.4 per cent chance of the dependent variable buying decisions is caused by the independent variable convenience of shopping, variety of brands, quality of products, online discounts, delivery services, and secure online payment.

4 Conclusion

Lingerie shopping in India has progressed from small, packed shops staffed by inexperienced salespeople to well-equipped portals with appropriate specialists. The apprehension of buying from a shopkeeper, who was sometimes male, often resulted in women missing out on the correct size and fit. It would not be an exaggeration to claim that online retailers have altered the way of shopping. The core ethos of these online shops has been education, especially on the Internet. Brands attempt to raise customer awareness and remove the stigma surrounding this category by means of meaningful and effective communication strategies. They seek to be viewed as authentic by eliminating the clutter and assisting consumers in making smarter choices with the facts and reviews that they have on their websites. As a result, a large consumer base has emerged that has responded enthusiastically to a previously uninspiring market sector. Women today are more willing to experiment with buying intimate apparel digitally.

This research attempts to conduct a decisive study of six variables derived from the elaborative literature review. The variables were the convenience of shopping, variety of brands, quality of products, online discounts, delivery services, and secure online payment that have a positive impact on the buying decisions of Indian women regarding lingerie products during online shopping.

The study results offer input and guidance to online retailers re-drafting/re-considering their strategic techniques for improving efficiency, increasing the level of purchasing decisions and standing out in an increasingly competitive market in the Internet age. To survive in an increasingly competitive market world, online retailers can re-evaluate all six factors that have a high effect on purchasing decisions and initiate and redesign their strategies accordingly. These variables serve as consumer input when shopping online, showing how they feel and what they want. This research might be useful in assessing and improving their performance.

The online lingerie industry is still in its infancy but has immense potential that is only waiting to be realised. The influx of many more foreign participants will only improve the Indian lingerie industry and provide its consumers with the best options. If not entirely, online retailers can be credited with a significant portion of growth of the Indian lingerie industry. As a result, the lingerie industry has a vast potential to explore and propel their brands for greater consumer loyalty through online purchase mode, while simultaneously increasing customer acquisition and driving sales at a faster pace. The dynamics of the Indian lingerie industry are encouraging enough for these firms to venture into an online business with confidence.

References

1. GUGNANI, A., BRAHMA, K. Growing potential of innerwear market in India [online]. IndiaRetailing [accessed 16 May 2021]. Available on World Wide Web: https://www.indiaretailing.com/2018/09/19/fashion.
2. DORAI, S., BALASUBRAMANIAN, N., SIVAKUMARAN, B. Enhancing relationships in e-tail: role of relationship quality and duration. *Journal of Retailing and Consumer Services*, 2021, **58**, 1–14, doi: 10.1016/j.jretconser.2020.102293.
3. SHANKAR, V., SMITH, A. K., RANGASWAMY, A. Customer satisfaction and loyalty in online and offline environments. *International Journal of Research in Marketing*, 2003, **20**(2), 153–175, doi: 10.1016/S0167-8116(03)00016-8.
4. LIMAYEM, M., KHALIFA, M., FRINI, A. What makes consumers buy from Internet? A longitudinal study of online shopping. *IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans*, 2000, **30**(4), 421–432, doi: 10.1109/3468.852436.

5. HIRST, A., OMAR, O.E. Assessing women's apparel shopping behaviour on the internet. *The Journal of Retail Marketing Management Research*, 2007, **1**(1), 32–40.
6. JAIN, R. Online spending dynamics of working women professionals in Bangalore city. *Indian Journal of Applied Research*, 2014, **4**(12), 320–323.
7. SINGH, P. Consumer's buying behaviour towards online shopping. *National Monthly Refereed Journal of Research in Commerce and Management*, 2014, **3**, 27–34.
8. RITA, P., OLIVEIRA, T., FARISA, A. The impact of e-service quality and customer satisfaction on customer behaviour in online shopping. *Heliyon*, 2019, **5**(10), 1–14, doi: 10.1016/j.heliyon.2019.e02690.
9. SAN MARTÍN, S., CAMARERO, C. How perceived risk affects online buying. *Online Information Review*, 2009, **33**(4), 629–654, doi: 10.1108/14684520910985657.
10. NISAR, T.M., PRABHAKAR, G. What factors determine e-satisfaction and consumer spending in e-commerce retailing? *Journal of Retailing and Consumer Service*, 2017, **39**, 135–144, doi: 10.1016/j.jretconser.2017.07.010.
11. PAPPAS, I.O., PATELI, A.G., GIANNAKOS, M.N., CHRISSIKOPOULOS, V. Moderating effects of online shopping experience on customer satisfaction and repurchase intentions. *International Journal of Retail and Distribution Management*, 2014, **42**(3), 187–204, doi: 10.1108/IJRDM-03-2012-0034.
12. DUARTE, P., E SILVA, S.C., FERREIRA, M.B. How convenient is it? Delivering online shopping convenience to enhance customer satisfaction and encourage e-WOM. *Journal of Retailing and Consumer Services*, 2018, **44**, 161–169, doi: 10.1016/j.jretconser.2018.06.007.
13. CORBITT, B.J., THANASANKIT, T., YI, H. Trust and e-commerce: a study of consumer perceptions. *Electronic Commerce Research and Applications*, 2003, **2**, 203–215, doi: 10.1016/S1567-4223(03)00024-3.
14. KRUH, W et al. *The truth about online consumers: 2017 Global online consumer report*. KPMG International, 2017.
15. TSIAKIS, T., STHEPHANIDES, G. The concept of security and trust in electronic payments. *Computers and Security*, 2005, **24**(1), 10–15, doi: 10.1016/j.cose.2004.11.001.
16. SCHLOSSER, A.E., WHITE, T.B., LLOYD, S.M. Converting website visitors into buyers: how website investment increases consumer trusting beliefs and online purchase intentions. *Journal of Marketing*, 2006, **70**(2), 133–148, doi: 10.1509/jmkg.70.2.133.
17. MARRIOTT, H.R., WILLIAMS, M.D. Exploring consumers perceived risk and trust for mobile shopping: A theoretical framework and empirical study. *Journal of Retailing and Consumer Services*, 2018, **42**, 133–146, doi. 10.1016/j.jretconser.2018.01.017.
18. LEE, S.J., AHN, C., SONG, K.M., AHN, H. Trust and distrust in e-commerce. *Sustainability,* 2018, **10**(4), 1–19, doi: 10.3390/su10041015.
19. KOTLER, P., ARMSTRONG, G., SWEE-HOON, A., SIEW-MANG, L., CHIN-TIONG, T., HONG-MING, Y.O. *Principles of marketing: an Asian perspective*. Singapore : Pearson Education, 2011.
20. SEBASTIANELLI, R., TAMIMI, N., RAJAN, M. Perceived quality of online shopping: Does gender make a difference? *Journal of Internet Commerce*, 2008, **7**(4), 445–469, doi: 10.1080/15332860802507164.
21. HINZ, O., ECKERT, J., SKIERA, B. Drivers of the long tail phenomenon: an empirical analysis. *Journal of Management Information Systems*, 2011, **27**(4), 43–70, doi: 10.2753/MIS0742-1222270402.
22. ARIFFIN, S.K., MOHAN, T., GOH, Y.N. Influence of consumers' perceived risk on consumers' online purchase intention. *Journal of Research in Interactive Marketing*, 2018, **12**(3), 309–327, doi: 10.1108/JRIM-11-2017-0100.
23. LEPKOWSKA-WHITE, E. Online store perceptions: how to turn browsers into buyers? *Journal of Marketing Theory and Practice*, 2004, **12**(3), 36–47, doi. 10.1080/10696679.2004.11658523.
24. GOLDFARB, A., TUCKER, C. Digital economics. *Journal of Economic Literature*, 2019, **57**(1), 3–43, doi. 10.1257/jel.20171452.
25. RAJENDRAN, S.D., WAHAB, S.N., LING, Y.W., YUN, L.S. The impact of logistics services on the e-shoppers' satisfaction. *International Journal of Supply Chain Management*, 2018, **7**(5), 461–469.
26. HEDIN, J., JONSSON, M., LJUNGGREN, J. Delivery performance: How to define and measure delivery performance in a triadic relationship: student thesis. Växjö University, Business administration and economics, 2006.
27. RAIJAS, A. The consumer benefits and problems in the electronic grocery store. *Journal of Retailing*

and Consumer Services, 2002, **9**(2), 107–113, doi: 10.1016/S0969-6989(01)00024-8.

28. BOUGIE, R., SEKARAN, U. *Research methods for business: a skill building approach*. Hoboken : Wiley, 2003.
29. VASKE, J.J., BEAMAN, J., SPONARSKI, C.C. Rethinking internal consistency in Cronbach's alpha. *Leisure Sciences*, 2017, **39**(2), 163–173, doi: 10.1080/01490400.2015.1127189.
30. NUNNALLY, J. C. *Psychometric theory 3E*. Tata McGraw-Hill education, 1994.
31. HAIR, J., BLACK, W., BABIN, B., ANDERSON, R. *Multivariate data analysis*. London : Prentice Hall, 2006.

Kura Alemayehu Beyene, Chirato Godana Korra
Bahir Dar University, Ethiopian Institute of Textile and Fashion Technology (EiTEX), Bahir Dar Ethiopia

Modeling for the Prediction and Evaluation of the Crimp Percentage of Plain Woven Fabric Based on Yarn Count and Thread Density

Postavitev modela za napovedovanje in ovrednotenje odstotka skrčenja za tkanino v vezavi platno na podlagi dolžinske mase preje in gostote niti

Original scientific article/*Izvirni znanstveni članek*
Received/*Prispelo* 8-2021 • Accepted/*Sprejeto* 11-2021

Corresponding author/*Korespondenčni avtor:*
Kura Alemayehu Beyene (MSc.)
Email: kuraalemayehu@gmail.com
Phone: +251910307004
ORCID ID: 0000-0002-2293-5048

Abstract

Nowadays, modeling is used for evaluating and controlling the weft crimp percentage before and after manufacturing plain woven fabrics. Also, modeling assists in estimating and evaluating crimp percentage without complex and time-consuming experimental procedures. The purpose of this study is to develop a linear regression model that can be employed for the prediction and evaluation of the weft crimp percentage of plain woven fabric. For this study, nine plain woven fabrics of 100% cotton were produced with three different wefts thread densities and weft yarn linear densities. From the findings, the effects of weft count and weft density on the weft crimp percentage of the fabrics were found to be statistically significant with a confidence interval of 95%. The weft crimp percentage showed a positive correlation with weft count and weft density. The weft count and weft density have multicollinearity in the model because the variance inflation factors (VIFs) values are greater than one, which are 1.70 & 1.20, respectively. The model was tested by correlating measured crimp percentage values obtained with a crimp tester instrument to the crimp percentage values calculated by a developed linear model equation. The result disclosed that the model was strongly correlated, with a confidence interval of 95% (R^2 of 0.9518). Furthermore, the significance value of the t-test is not significant for both the measured weft crimp percentage values and the calculated weft crimp percentage values, which means that they do not differ significantly. Crimp percentage is impacted by fiber, yarn, fabric structural parameters and machine setting parameters. This makes the crimp percentage difficult to control and study, but this developed model can be easily used by manufacturers or researchers for controlling and studying purposes. Thus, the model can be used to produce a fabric with a pre-controlled weft crimp percentage. It can also be used to evaluate and predict the weft crimp percentage before and after fabric production.
Keywords: crimp percentage, regression modeling, thread density, yarn count, plain-weave

Izvleček

Modeliranje se lahko uporablja kot orodje za ocenjevanje in nadzor odstotka skrčenja votka v tkanini v vezavi platno pred tkanjem ali po njem. Z modeliranjem se lahko izognemo dolgotrajnim in zapletenim eksperimentalnim postopkom *za določanje in vrednotenje skrčenja votka. Namen te študije je razviti linearni regresijski model za napovedovanje in ovrednotenje stkanja votka v tkaninah v vezavi platno. Za ta namen je bilo izdelanih devet tkanin v vezavi platno iz 100-odstotnega bombaža v treh različnih gostotah po votku in z uporabo votkovne preje z različno dolžinsko maso. Ugotovljeno je bilo, da so vplivi dolžinske mase votkov in gostot po votku na odstotek stkanja statistično pomembni, s 95-odstotnim intervalom zaupanja. Vrednost skrčenja votka je pokazala pozitivno korelacijo z dolžinsko maso votka in gostoto votkovnih niti. Vendar dolžinska masa votka in gostota votkovnih niti izkazujeta v modelu multikolinearnost, saj sta vrednosti faktorjev inflacije variance (VIFs) večji od ena, kar je 1,70 oziroma 1,20. Model je bil preizkušen z izračunom korelacije med izmerjenimi vrednostmi stkanja in vrednostmi stkanja, izračunanimi s pomočjo razvite linearne modelne enačbe. Rezultat je pokazal veliko koreliranje modela s 95-odstotnim intervalom zaupanja (R^2 0,9518). Tudi vrednosti t-testa niso pokazale statistično pomembnih razlik med izmerjenimi in izračunanimi vrednostmi stkanja. Odstotek stkanja votkovnih niti v tkanini je odvisen od številnih parametrov, kot so lastnosti vlaken, struktura preje in tkanine ter nastavitev strojne opreme. Zaradi številnih vplivov je odstotek stkanja votka težko nadzorovati, vendar se model lahko uporabi za nadzor in proučevanje le-tega tako s strani proizvajalcev kot raziskovalcev. Model lahko uporabimo za izdelavo tkanine z vnaprej načrtovanim odstotkom stkanja votka. Uporablja se lahko za ocenjevanje in napovedovanje odstotka skrčenja votka tudi pred izdelavo tkanine in po njej.*

Ključne besede: odstotek skrčenja, regresijsko modeliranje, gostota niti, dlžinska masa preje, platno

1 Introduction

There are various types of weave structures that are manufactured nowadays, such as plain, twill, honeycomb, satin and other derivatives. The weave architecture is constructed from the interlacement of two sets of yarn: weft and warp yarns. The yarn interlacement forms a crimp. A crimp is geometrically considered as the percentage excess of the length of the straight yarn axis over the cloth length or fabrics [1−3].

Crimp percentage could be affected by various factors, such as thread density of the warp and weft, loom setting, fabric structure and yarn count, amongst others. A theory can be proposed that the crimp percentage of the yarn of the woven fabric is directly related to the tension that is applied during weaving. The warp tension significantly affects both the warp and weft yarn crimp percentage. Also, the weft crimp percentage increases with the increase of warp tension [4, 5]. With an increase of the weft yarn count, the crimp percentage of weft yarn increases, whereas it reduces for the warp yarn at comparable weft densities. The series of yarn of the woven fabric is directly related to the coarseness and density of the other series of yarn [6, 7].

The crimp of warp and weft yarn in woven fabrics is an important parameter that influences several fabric properties such as fabric mass per unit area (GSM), surface roughness, strength, extensibility, thickness, compressibility, stress-strain relations, handle, and creasing. A higher number of interlacements results in wavier yarns and an increase in yarn crimp. The yarn crimps also influence the economics of the fabrics as they impact the quantity of yarn required to weave a fabric during manufacturing and a difference in the weight per unit area [8, 9].

Several researchers proposed different methods of crimp percentage measurements, such as how it can be calculated and how it affects the properties of fabrics. The yarn crimp percentage is majorly influenced during the manufacturing and technological finishing stages of the woven fabric. Predictive modeling has nowadays become a powerful tool that can deliver real value through its application and innovation to different textile industries. It forms an essential part of the research and development effort of many of the world's leading organizations and can be incredibly valuable for textile industries. Using linear modeling, it is possible to identify the effective features of crimp percentage in fabric structure and also to discover how crimp percentage influences the properties of woven fabrics. When the model is used in combination with good analysis and experimentation, it can enhance progress, save time, minimize cost, multiply effort, and efficiently use resources. The results are perceptible, available quickly, and projected appropriately.

In this research, a regression model was developed based on three thread densities and three counts in the weft direction of fabrics. Since crimp percentage is one of the main parameters of woven fabric construction, yarn crimp has a practical significance for designers; in particular, this parameter can be exploited to define fabric behavior during the manufacturing and finalization process in addition to defining material (yarn) consumption. Thereby, a designer on the loom can have the ability to analyze the input parameters for manufacturing plain woven fabrics and predict the behavior of weft crimp percentage in woven fabrics. It is also possible to detect that weft crimp percentage depending on the type of raw materials (which is cotton), yarn structure (which is weft count), and fabric geometry (which is weft density). The linear model provides a good basis for investigating, analyzing, predicting and evaluating weft crimp percentage during manufacturing, finishing treatment, and even after manufacturing, for testing and predictions.

2 Materials and methods

2.1 Materials

Nine plain woven fabrics, 100% cotton, were produced with different structural parameters by a Picanol air jet loom. The fabrics used for this study have three different weft densities (threads/cm) and three different weft yarn linear densities. Warp thread density, warp count, tension, loom speed, and relative humidity were kept constant, as shown in Table 1. After the fabrics production, each fabric was treated with a combined pretreatment process. The chemicals used were sodium hydroxide 3%, hydrogen peroxide 4%, sodium silicate 2%, wetting agent 0.5%, and EDTA 0.5 on the weight of the fabric and 1:10 liquor ratios. The efficiency of a combined pretreatment was assessed by the iodine solution test method as per AATCC and the samples showed a brown color and good water absorbency.

2.2 Experimental design

Central composite design experiments require a minimum number of trials for estimating the main effect and a lower number of runs, and allow sequential experimentation, which provides flexibility and time-saving in running the experiment and analysis [10]. Central Composite Design (CCD) with two independent variables (factors) was applied to investigate the effect of weft yarn count and weft density on the crimp percentage of a plain woven fabric in the weft direction. The experiment has 8 non-center and 5 center points. The total number of the run was 13 with five numbers of the replica, as shown in Table 2.

2.3 Experimental procedure

Five test specimens were prepared for measuring crimp percentage from each produced sample and conditioned at 65% ± 2% relative humidity and 20 °C ± 2 °C for a minimum of 24 hour before testing according to ASTM-D1776 practice for conditioning and testing textile materials. The weft crimp in the fabric samples was measured by the Shirley crimp tester instrument and the crimp percentage values of yarns were calculated according to the ASTM-D3883-04 standard using Equation 1.

$$Crimp\ \frac{Y-F}{F} * 100\ (\%) \tag{1}$$

where F is the distance between benchmarks on the yarn in the fabric and Y is the distance between benchmarks on the yarn after removal from the fabric and straightening. The values of the crimp percentages are depicted in Table 2 under the column of response. The data were used for model

Table 1: Construction parameters of the nine woven fabrics

Fabrics code	Weave type	Warp density (threads/cm)	Warsp count (tex)	Weft density (threads/cm)	Weft count (tex)
F1	Plain	24	29.5	18	14.76
F2	Plain	24	29.5	21	14.76
F3	Plain	24	29.5	24	14.76
F4	Plain	24	29.5	18	29.5
F5	Plain	24	29.5	21	29.5
F6	Plain	24	29.5	24	29.5
F7	Plain	24	29.5	18	42
F8	Plain	24	29.5	21	42
F9	Plain	24	29.5	24	42

Table 2: The experimental design for crimp percentage

Fabrics Code	Run	Factor 1	Factor 2	Response 1
		Count (tex)	Density (threads/cm)	Crimp percentage
F5	1	29.5	21	5.16
F6	2	29.5	24	5.96
F4	3	29.5	18	4.56
F7	5	42	18	6.56
F5	6	29.5	21	5.16
F1	12	14.76	18	3.80
F5	8	29.5	21	5.16
F5	9	29.5	21	5.16
F9	4	42	24	7.64
F5	10	29.5	21	5.16
F3	7	14.76	24	4.12
F2	11	14.76	21	3.88
F8	13	42	21	7.20

development and statistical analysis and evaluations using the Design-Expert software analysis of variance (ANOVA) were conducted.

2.4 Developing an empirical model for crimp percentage

The properties of the fabric are noticeably affected by crimp percentages, hence controlling the crimp percentage and studying the effects of crimp on the fabric properties is difficult because crimp is an uncontrollable factor. Thus, to make crimp percentage controllable, modeling the crimp percentage based on the yarn and fabric structural parameters is necessary. Using the developed model, the weft crimp percentage value can easily be determined or predicted . The measured weft yarn crimp percentage from the fabric samples was used to develop the model equation. The experimental results in Table 2 were given as input to the Design-Expert software for developing the model and for further analysis.
Design-Expert provides prediction equations (model) in terms of actual units and coded units. The coded equations are determined first and the actual equations are derived from the coded equations. To obtain the actual equation, each term in the coded equation is replaced with its coding formula shown in equation 2.

$$X_{coded} = \frac{X_{actual} - \bar{X}}{(X_{High} - X_{Low})/2}) \quad (2),$$

where X_{coded} are coded values of weft crimp percentage, X_{actual} is the actual weft crimp percentage, $\bar{X}$ is the mean values of a weft crimp percentage, X_{High} is the maximum values of weft crimp percentage, and X_{Low} is the minimum value of weft crimp percentage.

Although different parameters affect the weft crimp percentages of woven fabrics, assumptions are needed to obtain a reliable and valid model.
Assumptions:

- all the fibers have the same properties,
- the fabric is produced with a constant tension force,
- the twist factor of the yarn is maintained as per the standards,
- normal yarn elongation % is maintained,
- the cross-section of yarns is regarded as a circle,
- the fabric is produced with the same warp count and density,
- the model is only valid for cotton material and plain-weave;

Multiple regression or, in this case linear regression, is a collection of statistical techniques and methods that are useful in building the types of empirical models required in response surface methodology (RSM). There is a close connection between RSM and linear regression analysis [11, 12]. The most commonly used linear equation to fit the experimental data and to determine the output response is defined in equation 3.

$$\text{Crimp} = \beta_0 + \beta_1 A + \beta_2 B \ (\%) \qquad (3),$$

where β is the center point, β_1 is the coefficient of a weft count, β_2 is the coefficient of a weft density, A is weft count, and B is a weft density.

2.5 Model validity test

It is always necessary to examine the fitted model to ensure that it provides an adequate approximation to the true system values and verifies that none of the least-squares regression assumptions and rules are violated. Proceeding with the exploration and optimization of a fitted response surface will likely give poor or misleading results unless the model provides an adequate fit by inputting the weft crimp percentage values measured by a crimp tester instrument into the developed model equation [13–15].

2.6 Model test

A four plain woven fabric that was not used for model extraction purposes was used as the control model in the test measuring surface roughness values by the crimp tester instrument and to obtain the calculated crimp percentage values by the model equation. A structural parameter analysis (density and count) was done for the fabrics that were used for the model equation test purposes. The count of weft yarn from the fabric is measured according to ISO 7211-5 and the weft density of yarn was measured by using the ISO 7211-2 standard. Finally, the average value of each measured weft crimp percentage value of fabrics was used for calculating weft crimp percentage values by the developed model equation. Then, weft crimp percentage values of the fabrics were also measured by the Shirley crimp tester instrument. Finally, the correlation between the calculated and measured values of crimp percentage was determined through a plotted graph.

3 Results and discussion

3.1 Effects of count and density on the crimp percentage

The weft crimp percentage of the produced fabric was measured and calculated according to the ASTM-D3883-04 standard as shown in Table 2 under the response column and the Quantile-Quantile Plot implies that the collected data were normally distributed as shown in Figure 1. From the box plot in Figure 2, it can be observed that the collected data of weft crimp percentage have no outliers either the upper limit or lower limit. This implies that the collected data are normally distributed and can be used for further statistical analysis and modeling purposes.

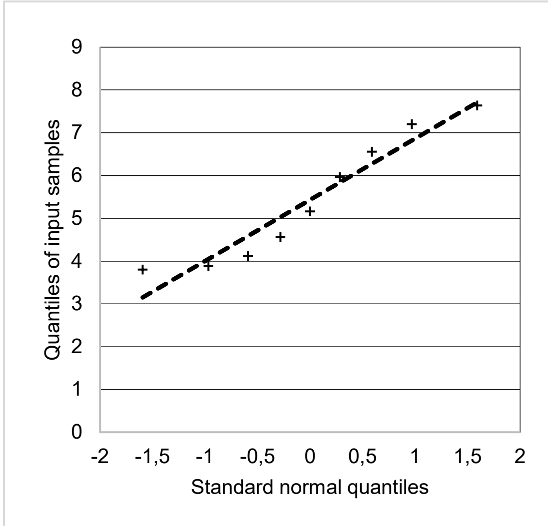


Figure 1: The Quantile-Quantile Plot of the input data vs. standard normal

The ANOVA Table 3 indicates that the linear model can be used to describe the crimp percentage of the fabrics based on yarn and fabric parameters, which are count and density, respectively. The F-value is 121.71 ($P < 0.0001$) which implies that the model is significant. There is only a 0.01% chance that an F- value this large could occur due to error. The P-values of less than 0.05 ($P < 0.05$) indicate the significance of the model terms. Both the model terms count and density are statistically significant at 95% of the confidence interval since they have a P- value of 0.0001 and 0.0027, respectively. The predicted R^2 of 0.9341 is in strong agreement with the adjusted R^2 of 0.9526 since the difference is less than 0.2, which ensures that there is a satisfactory adjustment of the model to the weft crimp percentage values. These indicate that the predicted R^2 shows the extent of the variance of the dependent (weft crimp percentage) variable that has been explained by independent (weft yarn count and weft density) variables in the model term. Moreover, the adjusted R^2 is the modified version of the predicted R^2 that shows the

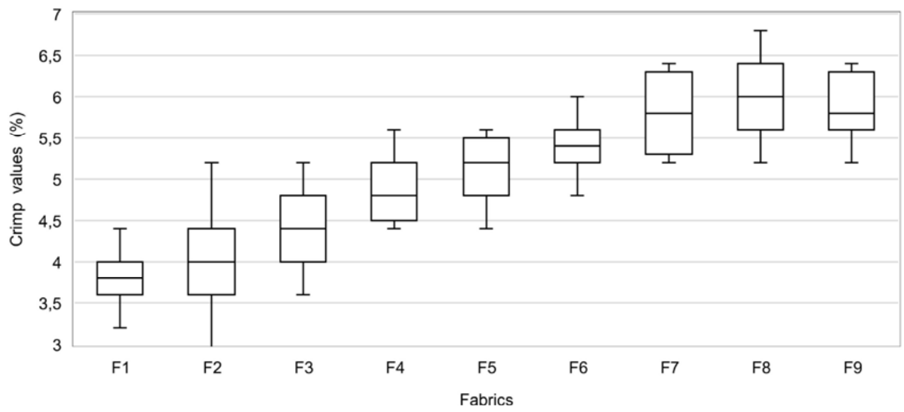


Figure 2: The box plot of the crimp percentage data for the nine woven fabrics

usefulness of the predictors (weft yarn count and weft density) in the model term. Thus, their difference should be less than 0.2 and even as it becomes smallesr, that signalls that the dependent variables were better explained or have strong correlations with the independent variable. However, their difference should not be greater than 0.2 [16, 17].

The effect of weft yarn count on the weft crimp percentage value of fabrics was observed. Weft crimp percentage values increase as the weft yarn count becomes coarser, while weft crimp percentage value decreases as the weft yarn becomes increasingly finer as shown in Figure 3. The coarser the yarn is, the more rigid it is and has a higher bending point, whereas finer yarn is less rigid and has a small bending point. This was due to the fact that coarser yarn can create higher waviness, while finer yarn creates lower waviness during the interlacement of the two yarns [7, 18]. Also, the weft crimp percentage values of the fabrics increase as the weft density of the fabrics increases, whereas the weft crimp percentage decreases as the weft density decreases as shown in Figure 3. This was because as the thread density of weft yarn increases, the weft and valley on the yarn increases. This is due to the tight interlacement of weft yarn over the warp. As the tightness or compactness of the fabrics increases, the weft yarn properly bends over the warp yarn, which results in an increase in the weft crimp percentage. On the other hand, the waviness of the weft yarn decreases as the weft density decreases in the plain woven fabrics, the result of which is a decrement in weft crimp percentage. This is because as the weft

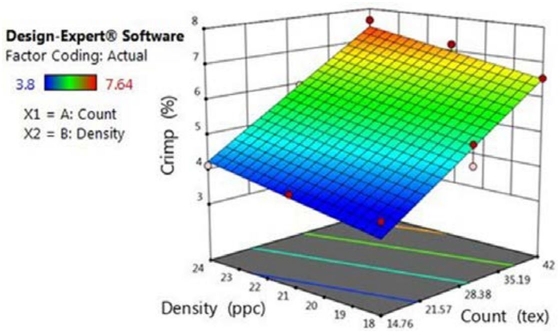


Figure 3: The effects of both density and count on weft crimp percentage

Table 3: ANOVA Table of regression

Source	Sum of Squares	Df	Mean Square	F-value	P-value	Decision
Model	21.95	2	10.98	121.71	< 0.0001	Significant
Count	20.61	1	20.61	228.56	< 0.0001	Significant
Density	1.41	1	1.410	15.660	0.0027	Significant
Residual	0.9018	10	0.0902			
Lack of Fit	0.7218	6	0.1203	2.670	0.1802	Not significant
Pure Error	0.1800	4	0.0450			
Cor Total	22.85	12				

density decreases the fabric tightness also decreased [19, 20].

The coefficient estimate represents the expected change in response per unit change in factor value when all the remaining factors are held constant. For instance, if weft count increases by one unit, the response (weft crimp percentage) increases by 1.59 units while keeping the weft density and other parameters constant. Also, if weft density increases by one unit, the response (weft crimp percentage) increases by 0.4667 units, while keeping the weft count and other parameters constant as is shown in Table 4. The coefficients are adjustments around that average based on the factor settings. The variance inflation factor (VIF) quantifies the extent of correlation between one predictor and other predictors in a model. A VIF can be computed for each predictor in a predictive model (21, 22). The variance inflation factors (VIF) for the predictor weft count, for example, indicate that the variance of the estimated coefficient of weft count is inflated by factor 1.70 because weft count is highly correlated with weft density in the model, as shown in Table 4. The factors are orthogonal when the VIFs values are 1; VIFs values greater than 1 indicate multi-collinearity, so the higher the VIF, the more severe the correlation of factors. As a rough rule, VIFs less than 10 are tolerable (16, 23). Thus, weft count and weft density have multicollinearity in the model term because the VIFs values are greater than one.

3.2 Model equation for crimp percentage

The actual model equation was developed by using the weft crimp percentage values of the nine samples that were measured by the crimp tester instrument and the crimp percentage was calculated by Equation 1. The equation in terms of actual factors (count and density) can be used to make predictions about the crimp percentage for the given levels of each factor. This equation cannot be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space [24, 25]. The center point value and the coefficient values for each weft yarn count and weft density of the actual model equation were not used to interrelate their relationships. Thus, the actual model equation 4 can be used for the prediction and evaluation of the weft yarn crimp percentage from the given yarn and fabric structural parameters.

$$Weft\ crimp = -1.1122 + 0.1177 \times \text{Count(Weft)} + + 0.1506 \times \text{Density(Weft)}(\%) \quad (4),$$

where, –1.1122 is the center point of the model, +0.1177 is the coefficient of weft count and +0.1506 is the coefficient of weft density. By substituting the weft count and weft density values in Equation 4, the weft crimp percentage can be easily calculated.

The sign of the center point of the model is negative but does not have any effect on the model term unless the independent can be zero. So, there is no single way that the independent factors (weft yarn count and weft density) could be zero. The center point is a model described as the mean response value when all predictor variables are set to zero [26, 27]. Mathematically, that is correct. However, a zero setting for all predictors that are weft yarn count and weft density in the model, is often an impossible/nonsensical combination. If all of the predictors cannot be zero, it is impossible to interpret the value of the center point [27].

3.3 Model validity test

The model validation was conducted by using the crimp percentage values obtained from the crimp formula Equation 1 and the calculated crimp percentage values from the model equation 4 for the nine plain woven fabrics that were used earlier for the model equation extraction purpose, as shown in Table 5. Finally, the correlation between the calculated and measured values was determined through plotted graphs. It is necessary to examine the effect of the developed model equation to ensure that it provides an adequate approximation to the true values and verifies that none of the least-squares regression assumptions and rules are violated [10, 13].

Table 4: Coefficients in Terms of coded factors

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	5.26	1	0.0907	5.06	5.46	
A-Count	1.59	1	0.1342	1.30	1.89	1.70
B-Density	0.4667	1	0.1331	0.1700	0.7633	1.20

Table 5: Crimp percentage measured and estimated values used for model validity test

Fabric code	Warp density (threads/cm)	Warp count (tex)	Weft density (threads/cm)	Weft count (tex)	Measured crimp (%)	Estimated crimp (%)
F1	24	29.5	18	14.76	3.8	3.335
F2	24	29.5	21	14.76	3.88	3.787
F3	24	29.5	24	14.76	4.12	4.238
F4	24	29.5	18	29.5	4.56	5.070
F5	24	29.5	21	29.5	5.16	5.522
F6	24	29.5	24	29.5	5.96	5.973
F7	24	29.5	18	42	6.56	6.541
F8	24	29.5	21	42	7.2	6.993
F9	24	29.5	24	42	7.64	7.445

As shown in Figure 4, the proposed model equation 4 can properly correlate the experimentally measured data from crimp formula Equation 1 at the confidence interval of 95% (R^2 of 0.95864). Thus, the model was valid because the measured value obtained by crimp percentage formula Equation 1 is articulated further by the calculated value obtained by the developed model equation 4, as shown in Figure 4. The broken blue line represents the calculated weft crimp percentage obtained by the developed model equation 4 and the green dot-triangle line represents the measured weft crimp percentage value obtained by crimp percentage formula Equation 1. Both have a better correlation or approximation, with a straight-line drawn linearly by the continuous yellow line in Figure 4. Thus, the model equation 4 correctly predicts the weft crimp percentage of the plain woven fabrics that were used for the model extraction purpose.

3.4 Model test

The model efficiency was tested by using four different fabrics that were not previously used for the model equation extraction. The fabric's properties were studied and the weft density and linear density were identified by using the ISO 7211-5 and ISO 7211-2 standards, as shown in Table 6. The model test helped to determine the accuracy and reliability of the model equation by correlating the measured and calculated values through plotted graphs. If the correlation percentage value was higher, then this means that the model drives accurate and reliable results. Table 6 shows the fabrics parameters used for the crimp percentage model test.

The correlation between the crimp percentage values obtained by the formula Equation 1 and the crimp percentage values from the developed model equation 4 was found to be strongly correlated with R^2 of 0.9518 at a 95% degree of freedom as shown

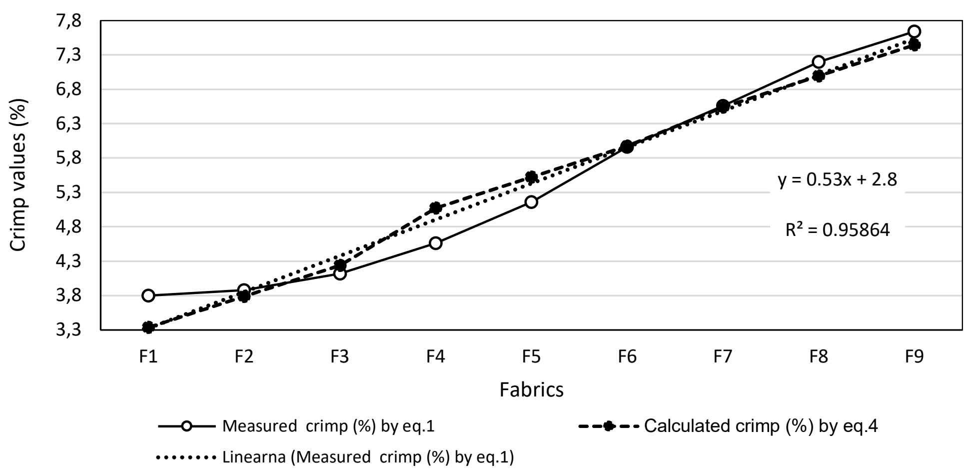


Figure 4: The correlation for measured weft crimp percentage values by the crimp tester instrument and the estimated weft crimp percentage value by the model equation for model validity test

Table 6: Fabrics parameters used for crimp percentage model test

Fabric code	Weave type	Linear density (tex)		Thread density (1/cm)		Crimp (%)	
		Warp	Weft	Warp	Weft	Measured	Estimated
M1	Plain	32	32	32	28	6.58	6.870286
M2	Plain	20	20	20	20	4.48	4.253289
M3	Plain	36	36	21	21	6.448	6.287084
M4	Plain	34	34	28	20	5.62	5.901108

Table 7: Independent samples test

		Equality of variances		t-test for equality of means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean difference	Std. error difference	95% confidence interval of the difference	
									Lower	Upper
Weft crimp (%)	Equal variances assumed	.018	0.89	−.06	6	0.954	−0.0443	0.741	−1.858	1.769
	Equal variances not assumed	.018	0.89	−.06	6	0.954	−0.0443	0.741	−1.867	1.778

in Figure 5. Thus, the model equation can be used for the prediction and evaluation of weft crimp percentages for fabrics which are a hundred percent cotton plain woven that may have different weft count and weft density.

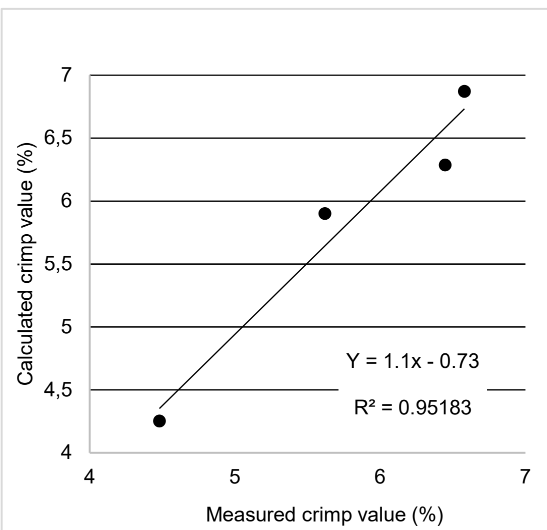


Figure 5: The correlation for measured and calculated weft crimp percentage for the model test

The model equation capacity is also checked by independent samples t-test. Depending on the t-test that is used, a sample mean to a hypothesized value, the means of two independent samples, or the difference between paired samples can be compared. As shown in Table 7, the group means are not statistically significantly different because the value in the "Sig. (2-tailed)" is greater than 0.05. Looking at the group statistics in Table 7, it can be observed that the measured weft crimp percentage values by the crimp tester instrument has no difference when it is compared to the weft crimp percentage calculated by the developed model Equation 4. Thus, as it is not significant, then it can be concluded that the model capacity of weft crimp percentage is properly explained by weft thread density and weft yarn count.

4 Conclusion

The weft yarn count and weft density were used for the extraction of a weft crimp percentage model equation. All the fabrics used in this research work were produced on the same machine under the same conditions. The model equation was statistically significant at a confidence interval of 95%. It can adequately be used to describe the weft crimp percentage of plain woven fabrics. The weft yarn crimp percentage has a positive correlation with weft count and weft density for constant warp density and warp yarn count. The weft count and weft density has multicollinearity in the model term because the VIFs values are greater than one. To produce fabrics with controlled and predetermined weft crimp percentages, the weft yarn linear density and weft density should be taken into consideration during production. The model was validated and tested by correlating measured weft crimp percentage values by a crimp percentage tester instrument and calculated weft crimp percentage values by the developed linear model equation. It discloses that the model was strongly correlated at the confidence interval of 95% with an R^2 0.9586 and R^2 of 0.9518, respectively. Also, the significance value of a t-test is not significant for both the measured weft crimp percentage values and calculated weft crimp percentage values. Thus, the model can be used to produce plain woven fabrics with a controlled weft crimp percentage and also for the evaluation and prediction of weft crimp percentage of plain woven fabrics. This study should be followed by further research and investigation because count and density are not the only factors that affect the weft crimp percentage properties of woven fabrics. This research could be extended in the future by considering fiber type, yarn parameters, and their alignment in fabric structures, either in warp and weft direction or the machine setting parameters.

Acknowledgment

The corresponding author is extremely grateful to my family for their love, prayers, caring and sacrifices in preparing me for my future. I wouldn't be here today if you weren't MOM (Itukoo). Thank you for always being there as I continue to navigate these early years of my life. I am everything I am because you loved me, Aster Sileshi (MOM).

Reference

1. HUA, T. Fabric making technologies. In *Handbook of fibrous materials*. Edited by Jinlian Hu, Bipin Kumar and Jing Lu. Weinheim : Wiley, 2020, 477–498, doi: 10.1002/9783527342587.ch19.
2. PEIRCE, F.T. 5 - The geometry of cloth structure. *Journal of the Textile Institute Transactions*, 1937, **28**(3), T45–T96, doi: 10.1080/19447023708658809.
3. SIRKOVÁ, B.K., MERTOVÁ, I. Prediction of warp and weft crimp in the construction of dobby woven fabrics. *The Journal of The Textile Institute*, 2020, **111**(10), 1401–1409, doi: 10.1080/00405000.2019.1701967.
4. AFROZ, F., SIDDIKA, A. Effect of warp yarn tension on crimp% in woven fabric. *European Scientific Journal*, 2014, **10**(24), 202–207.
5. OZKAN, G., EREN, R. Warp tension distribution over the warp width and its effect on crimp distribution in woven fabrics. *International Journal of Clothing Science and Technology,* 2010, **22**(4), 272–284, doi: 10.1108/09556221011048295.
6. ALA, D., BAKICI, G.G.E. Effects of weft count and weft density on yarn crimp% of unbleached and bleached 3/1(s) twill woven fabrics. *Journal of Textile Engineering*, 2017, **24**(108), 254–259, doi: 10.7216/1300759920172410804.
7. MERTOVA, I., NECKAR, B., ISHTIAQUE, S.M. New method to measure yarn crimp in woven fabric. *Textile Research Journal*, 2015, **86**(10), 1084–1096, doi: 10.1177/0040517514551464.
8. DAS, A., KOTHARI, V.K., BALAJI, M. Studies on cotton–acrylic bulked yarns and fabrics. Part II: fabric characteristics. *The Journal of The Textile Institute*, 2007, **98**(4), 363–376, doi: 10.1080/00405000701550098.
9. LORD, P.R. *Handbook of yarn production: technology, science and economics*. Cambridge : Woodhead Publishing, 2003, 1–17.
10. MYERS, R.H., MONTGOMERY, D.C., VINING, G.G., BORROR, C.M., KOWALSKI, S.M. Response surface methodology: a retrospective and literature survey. *Journal of Quality Technology*, 2004, **36**(1), 53–77, doi: 10.1080/00224065.2004.11980252.
11. BAŞ, D., BOYACI, İ.H. Modeling and optimization I: usability of response surface methodology. *Journal of Food Engineering*, 2007, **78**(3), 836–845, doi: 10.1016/j.jfoodeng.2005.11.024.
12. SADA, S. Modeling performance of response surface methodology and artificial neural network. *Journal of Applied Sciences and Environmental Management*, 2018, **22**(6), 875–881, doi: 10.4314/jasem.v22i6.6.
13. BRAUN, M.T., OSWALD, F.L. Exploratory regression analysis: a tool for selecting models and determining predictor importance. *Behavior Research Methods*, 2011, **43**(2), 331–339, doi: 10.3758/s13428-010-0046-8.
14. KHURI, A. Introduction to linear regression analysis, fifth edition by Douglas C. Montgomery, Elizabeth A. Peck, G. Geoffrey Vining (short book review). *International Statistical Review*, 2013, **81**(2), 318–319, doi: 10.1111/insr.12020_10.

15. RYAN, T.P., GRAY, J.B. Introduction to regression modeling. *Journal of Quality Technology*, 2006, **38**(4), 376–377, doi: 10.1080/00224065.2006.11918625.
16. GREENLAND, S. Valid P-values behave exactly as they should: some misleading criticisms of P-values and their resolution with S-values. *The American Statistician*, 2019, **73**(sup1), 106–114, doi: 10.1080/00031305.2018.1529625.
17. MAQSOOD, M., HUSSAIN, T., NAWAB, Y., SHAKER, K., UMAIR, M. Prediction of warp and weft yarn crimp in cotton woven fabrics. *The Journal of The Textile Institute*, 2015, **106**(11), 1180–1189, doi: 10.1080/00405000.2014.981041.
18. HARI, P.K. 1 - Types and properties of fibres and yarns used in weaving. In *Woven textiles: principles, technologies and applications*. Edited by Kim Gandhi. 2nd edition. Cambridge : Woodhead Publishing; 2020, 3–34, doi: 10.1533/9780857095589.1.3.
19. KADI, N. The effect of warp and weft variables on fabric's shrinkage ratio. *Journal of Textile Science & Engineering,* 2015, **5**(2), 1–8, doi: 10.4172/2165-8064.1000191.
20. CRANEY, T.A., SURLES, J.G. Model-dependent variance inflation factor cutoff values. *Quality Engineering*, 2002, **14**(3), 391–403, doi: 10.1081/QEN-120001878.
21. MIDI, H., SARKAR, S.K., RANA, S. Collinearity diagnostics of binary logistic regression model. *Journal of Interdisciplinary Mathematics*, 2010, **13**(3), 253–267, doi: 10.1080/09720502.2010.10700699.
22. DORMANN, C.F., ELITH, J., BACHER, S., BUCHMANN, C., CARL, G., CARRÉ, G., et al. Collinearity: a review of methods to deal with it and a simulation study evaluating their performance. *Ecography*, 2013, **36**(1), 27–46, doi: https://doi.org/10.1111/j.1600-0587.2012.07348.x.
23. BEYENE, K.A., SAMPATH, V. Modeling surface roughness for prediction and evaluation of bedsheet woven fabric. In *International Conference Proceedings CTA- 2019, EiTEX, BDU, Ethiopia*. Edited by Tamrat Tesafye and Berihun Bizuneh. Bahir Dar : Ethiopian Institute of Textile and Fashion Technology (EiTEX), 2019, 42–48.
24. CAVAZZUTI, M. *Optimization methods: from theory to design scientific and technological aspects in mechanics*. Berlin, Heidelberg : Springer, 2013, 13–42.
25. ENDERS, C.K., TOFIGHI, D. Centering predictor variables in cross-sectional multilevel models: a new look at an old issue. *Psychological Methods*, 2007, **12**(2), 121–138, doi: 10.1037/1082-989X.12.2.121.

Dragana Kopitar, Zeljka Pavlovic, Zenun Skenderi, Zlatko Vrljicak
University of Zagreb, Faculty of Textile Technology, Department of Textile Design and Management, Prilaz baruna Filipovića 28a, 10000 Zagreb, Croatia

Comparison of Double Jersey Knitted Fabrics Made of Regenerated Cellulose Conventional and Unconventional Yarns

Primerjava desno-desnih pletiv iz regeneriranih celuloznih vlaken, izdelanih iz konvencionalnih in nekonvencionalnih prej

Original scientific article/*Izvirni znanstveni članek*
Received/*Prispelo* 10-2021 • Accepted/*Sprejeto* 11-2021

Corresponding author/*Korespondenčni avtor:*
Prof DrSc Zenun Skenderi
E-mail: zenun.skenderi@ttf.hr
Phone: +385 1 3712 577
ORCID ID: 0000-0003-0758-1111

Abstract

The development of new spinning technologies has produced cheaper yarns and with it, research into the production and application of woven and knitted fabrics from unconventional yarns. The tensile properties of knitted fabrics made of regenerated cellulose fibres (viscose, Tencel™ and modal) of the same count (20 tex) using ring, rotor and air-jet spun yarn were studied. The force/elongation diagram was analysed in order to detect elastic and plastic areas as well as the area of elastoplastic deformations responsible for the behaviour of knitted fabrics. The yarn raw material affects the elastic area of knitted fabrics made from different yarn structures in the course direction whereby the highest elastic area was obtained in the case of ring spun yarns followed by air-jet and finally rotor spun yarns. Regardless of the raw material, the elastoplastic area of the knitted fabric in the wale direction is the lowest for ring spun yarns. There is no visible trend of knitted fabric elastoplastic areas in the wale direction regarding the yarn type and raw material.
Keywords: regenerated cellulose fibres, conventional and unconventional spun yarn, double jersey fabric, tensile properties, elastic and plastic deformation

Izvleček

Razvoj novih tehnologij predenja je pripomogel k izdelavi cenejših prej, s tem pa tudi k raziskavam pri izdelavi in uporabi tkanin in pletiv iz nekonvencionalnih vrst predivnih prej. V prispevku je opisana raziskava nateznih lastnosti pletiv, izdelanih iz regeneriranih celuloznih vlaken (viskoza, Tencel™ in modal). Preje z enako linearno gostoto (20 tex) so bile izdelane po prstanskem, rotorskem in curkovnem postopku predenja. Diagrami sila-raztezek so bili analizirani, da bi ugotovili lastnosti elastičnih in plastičnih območij ter območja viskoelastičnih deformacij, ki so odgovorne za specifično obnašanje pletiv. Vrsta materiala, iz katerega so izdelane preje, vpliva na elastično območje pletiv, izdelanih iz različnih vrst prej v smeri zančnih vrst. Največje elastično območje je imela prstanska preja, sledila je curkovna in nazadnje rotorska preja. Ne glede na vrsto materiala je bilo viskoelastično območje v smeri zančnih stolpcev najmanjše pri prstanski preji. Pri viskoelastičnih območjih pletiv v smeri zančnih stolpcev ni razpoznavnega trenda glede na vrsto preje in vlaken.

Ključne besede: regenerirana celulozna vlakna, konvencionalne in nekonvencionalne predivne preje, desno-desno pletivo, natezne lastnosti, elastična in plastična deformacija

1 Introduction

In the late 1960s, the disadvantages of ring spinning machines (power consumption as well as maximum production speeds) led to the development of various spinning techniques that provide higher production speeds [1]. In the late 1960s and early 1970s, one of the new, completely different spinning systems was introduced which competed with the ring spinning system, i.e. the rotor spinning system. The rotor spinning system has lower production costs and is suitable for further automation; however, with limitations in the production of finer yarn counts (only medium and coarser yarns). Further development of higher production technologies, regarding the ring spinning technology, and finer yarns, regarding the rotor system, brought about the air-jet spinning system. In addition to the air-jet system, friction and wrap spinning systems were introduced as well, although all three mentioned systems were accepted with varying degrees of acceptance [1]. The superiority of the air-jet system over the ring and especially the rotor system was the possibility to produce finer yarn counts (in the range from 7.5 tex to 12 tex). The development of new spinning technologies has resulted in many different types of research that deepen the understanding of yarn structure as well as the structure of textile products made of new, the so-called unconventional yarns. New regenerated cellulose fibres find a wide range of applications in the clothing industry, especially for clothing worn close to the skin, as they offer very good comfort. Previous studies showed that the raw material composition of the yarn as well as yarn type have a significant influence on the properties of knitted fabrics. Regenerated cellulose fibres (viscose, modal, Viloft®, MicroModal®, lyocell and bamboo) were spun in conventional yarn counts for ring spun yarns from 19.7 tex to 21.1 tex, commercially used in the clothing industry (underwear, sportswear, T-shirts) [2]. Basic physical-mechanical yarn properties showed, due to the fibre type, significant differences. Tenacity ranged from 11.7 cN/dtex to 28.3 cN/dtex, elongation from 9.2% to 14.2%, *CVm* from 10.5% to 16.1%, number of thin places from 0 to 75, thick places from 1.3 to 142.5, neps from 25 to 326.3 and hairiness from 6.12% to 10.6%. The investigation of the influence of the fibre raw material on yarn tensile properties showed a significant influence of the raw materials tested in dry and wet state [3]. Yarns were conventional ring spun yarns from cotton, viscose and polyester of similar count (from 14 tex to 17 tex), paper yarns being produced by twisting Manila hemp paper fibres. The paper yarn count ranged from 19 tex to 33 tex. PES yarns have the highest percentage of elongation in the dry state, whereas paper yarns have the lowest. Unlike elongation, paper yarns have the highest breaking force and cotton yarns the lowest. A further investigation of the influence of the yarn raw material (100% cotton and 95%/5% cotton/Lycra) and the knitted structure (single jersey and 1 × 1 rib knitted fabric) on the tensile properties showed a significant influence of both the yarn raw material and the knitted structure [4].

The influence of conventional and compact ring spun yarns spun from American Upland cotton fibres spun in three yarn counts (19.7 tex, 14.8 tex and 11.8 tex) and the same twist factor ($\alpha m = 134$) on the tensile strength, pilling and abrasion properties of fabrics was investigated [5]. The results of tested yarn properties (tensile strength, unevenness and hairiness) showed that compact yarns of all counts had higher tenacity and elongation at break, less yarn unevenness, fewer thick places and neps, but a higher number of thick places and less yarn hairiness. Better properties of compact yarns could be found in a better fibre orientation compared to ring yarns. The fabrics made of compact yarns showed higher tensile strength, the reason being better strength of compact yarns, as the differences in the strength values of fabrics were similar to the differences in the strength between yarns.

The authors Suzuki and Sukigara investigated tensile properties and plain knitted fabric compression, bending and torsion properties, where knitted fabrics were made by conventional ring spun yarns, vortex and open-end spun yarns from rayon fibres [6]. The authors investigated the influence of different spinning systems on the bending and torsion properties of plain knitted fabrics. The authors found out that vortex spinning systems produce yarn structures that differ from ring and open-end spinning; however, they could not find a clear relationship between the mechanical properties of the fabric and yarn.

The dimensional stability of knitted fabrics is one of the most discussed areas in the research field of knitted fabric production. Many authors concentrate on research into the dimensional stability of knitted fabrics; however, only few on the influence of yarn type and yarn raw materials on fabric construction and tensile properties [7]. The influence of the yarn spinning technology on the spirality of jersey fabrics showed that yarns produced with different spinning technologies (ring, rotor, friction and air-jet spinning) affect the spirality of knitted fabrics differently [8].

In addition to different yarn types, the influence of cellulose yarns on the dimensional properties of knitted fabrics showed a significant effect of changes in stitch length on course and wale spacing [9]. The investigation of the physical-mechanical parameters of different yarn types (ring, rotor and air-jet) made of modal fibres showed significant differences in unevenness and yarn faults, hairiness and tensile properties [10].

However, the literature review showed that the influence of different yarn structures and fibre types on the tensile properties of knitted fabrics produced with the same machine parameters has not been systematically researched. In this paper, the tensile properties of knitted fabrics were investigated for spun yarns produced from regenerated cellulose fibres (viscose, Tencel™, modal) using the ring, rotor and air-jet systems. The force-elongation diagram was analysed to determine the elastoplastic deformation range (i.e. area between elastic and plastic deformation) that is responsible for the behaviour of the knitted fabric in use. The part of the diagram where elastoplastic deformations occur is particularly interesting for knitted fabrics used in the manufacturing of recreational clothing and/or clothing with a compression ratio from 0.5 kPa to 1.5 kPa. Testing the tensile properties, the moment of knitted fabric breakage, the maximum force and elongation at break is not disputable. However, it is not always easy to determine the elastoplastic area or the beginning of the permanent deformation of the knitted fabric. In the case of knitted fabrics made of yarns of different raw materials, fineness and structure, this area, i.e. the limit area of elasticity and area of permanent deformation, has not been sufficiently investigated. The mentioned limit area and area of permanent deformation are very important in the production of quality recreational clothing, especially compressional recreational clothes or clothing for professional athletes.

2 Materials and methods

2.1 Yarn and knitted fabric

The ring, rotor and air-jet spun yarns with a nominal count of 20 tex made of viscose, Tencel™ and modal fibres with a count of 1.3 dtex and length of 38 mm were spun. The number of twists for viscose ring spun yarns was 745 m^{-1}, 780 m^{-1} for Tencel™ and 746 m^{-1} for modal ring spun yarns. The rotor yarn twists were 750 m^{-1} according to the end use of spun yarns, i.e. for knitting. The viscose, Tencel™ and modal ring spun yarn were produced with the following procedure: preparation process (opening, blending and mixing), carding process, spinning preparation (drawing, pre-spinning and ring spinning), winding and cleaning. The yarns were spun using a Zinser 351 ring-spinning machine (ring diameter: 42 mm, ring type: f2, spindle speed: 16,500 min^{-1}), wound up and cleaned on an Autoconer X5. The rotor spun yarns made of viscose, Tencel™ and modal fibres were produced using the fibre preparation processes (opening, blending), carding, spinning preparation (drawing) and rotor spinning using a Schlafhorst A8 rotor spinning machine. The air-jet spun yarns were made of viscose, Tencel™ and modal fibres using the preparation (opening, blending) and carding process, spinning preparation (three drawing passages) and air-jet spinning using a Rieter J 20 machine. A double bed circular knitting machine was used to knit fabrics. The machine is generally used for knitting plain double-knit jersey fabrics intended for the production of underwear. It is recommended to knit with single cotton yarns with counts from 12 tex to 36 tex, as the machine gauge is E17. It has 8 knitting systems; therefore, it was necessary to prepare 8 yarn packages for each yarn group. To control the tension of the yarn fed to the knitting system, Coni Memminger IRO positive feeders were used. The force amounted to 3 cN ± 1 cN. The fabric take-down was performed with two pairs of rollers located 70 cm away from the knitting zone. The fabric was not wound onto a fabric roll, but it was plaited down on the tray below the take down rollers. Viscose, Tencel™ and modal ring, rotor and air-jet spun yarns with a nominal count of 20 tex were used to knit the fabrics.

2.2 Test methods for yarns and knitted fabrics

The count of yarns was determined according to the ISO 2060:2008 standard, while ring spun yarns were twisted according to 2061:2015. The twist of rotor spun yarn was determined according to machine parameters (rotor speed), while the air-jet yarn twists were determined according to air pressure (vortex). The twist of rotor spun yarn was determined according to machine parameters (rotor speed), while the twist of air-jet spun yarn was determined according to air pressure (vortex). The yarn tensile properties were determined in accordance to the standard ISO 2062:2009 Textiles – Yarns from packages – Determination of single-end breaking force and elongation at break using constant rate of elongation (CRE) tester. The measurement of tensile properties was made on an Uster Tensorapid 4 instrument, with 100 measurements per package of each yarn type. The images of the ring, rotor and air-jet spun yarn structure were taken with a Dino-Lite digital microscope (constant magnification of 60×).

The tensile properties of knitted fabrics were measured in the course and wale directions with 50 mm wide and 200 mm long samples. The distance between the grippers of the tensile strength tester was 100 mm. Tensile properties were tested on a STATIMAT M tensile tester according to the standard ISO 13934-1. The results of breaking force and breaking elongation, work of rupture, strength and the force-elongation (*F*/*Ɛ*) diagram were determined. The force-elongation diagrams obtained were analysed as follows.

The knitted fabric is subjected to the effect of the tensile force due to the tension elongation that occurs. The *F*/*Ɛ* diagram of knitted fabrics can be divided into three main areas, i.e. elastic area, elastoplastic area and plastic area. In the first, elastic area (from point 0 to T1), the action of the tensile force causes a certain amount of elongation due to the movement of yarn within the knitted structure (cf. Figure 1). In the region from 0 to T1, the stress and strain are not proportional. However, if we remove the load, the body returns to its original dimension. The elastic part of the knitted fabric on the *F*/*Ɛ* curve is linear. In the non-linear elastoplastic or viscoelastic area (from point T1 to point T2), besides the yarn movement within the structure, a loosening of yarns occurs. In the non-linear elastoplastic area (from point T1 to point T2), besides the thread movement within the structure, the threads loosen. Point T2 is the point of inflexion after which the third area begins up to point T3, the area of plastic permanent deformation of the knitted fabric. In point T3 (knitted fabric breakage), individual yarns within the knitted fabric structure break until the complete fabric breakage occurs. The tangents at points T1 and T2 intersect in point T4, which is the point of critical elongation. Critical elongation is associated with force and elongation where the knitted fabric is tightened and the transition of the knitted fabric from the relaxed to the solid state occurs [9].

In the research, the main area of interest is the elastoplastic area or the limit area of elasticity and the area of permanent deformation of knitted fabrics. From the results obtained, parts of the elastic, elastoplastic and plastic surface of knitted fabrics with different yarn structure and fibre type were calculated.

3 Results and discussion

The fineness of yarns is uniform and ranges from 19.9 tex to 20.5 tex with a low coefficient of variation

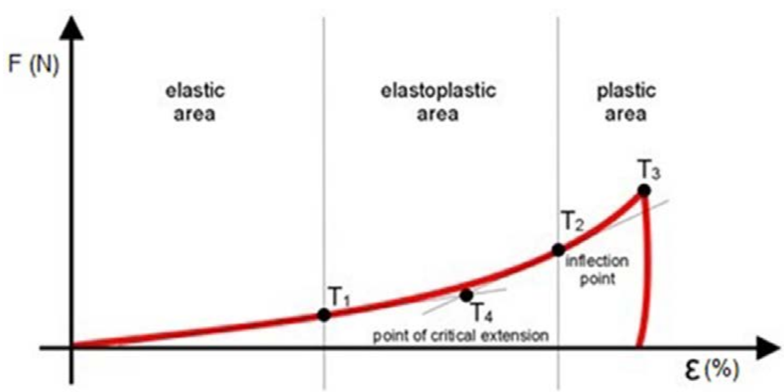


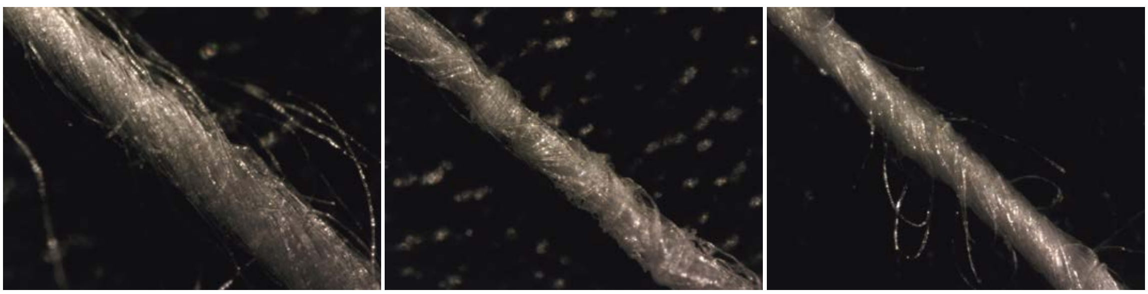
Figure 1: Knitted fabric F/Ɛ diagram

(in the range 0.3% to 1.3%), indicating high quality yarns.

Generally, yarn twist number is defined related to the yarn end use. The yarns used in the experiment are intended for the knitting process and have uniform twists with a low coefficient of variation (1.9% to 4.0%). The twist number of ring spun yarns slightly differs with regard to different raw material, i.e. viscose ring spun yarns have 744.7 m^{-1}, modal 746.1 m^{-1} and Tencel™ spun yarns have 779.7 m^{-1}. The nominal twist number of rotor yarns calculated from the rotor speed amounted to 750 twists per meter. The high pressure of the air in the rotating vortex was 0.6 MPa. The number of twists of all tested yarns was uniform, with a twist coefficient ranging from 3,280 to 3,350 m^{-1} $tex^{0.5}$.

Ring, rotor and air-jet spinning processes produce yarns with completely different structures and thus yarns with different properties. Figure 2 shows the yarn structure with characteristic twists of ring, rotor and air-jet spun yarns. The Tencel™ ring spun yarn consists of straight and parallel fibres twisted in the Z direction (cf. Figure 2a). Figure 2b shows the Tencel™ rotor yarn with disoriented fibres wrapped around the folded core. Tencel™ air-jet yarn fibres are tightly wrapped around the core of parallel, straight fibres (cf. Figure 2c).

The values of the yarn tensile properties, i.e. maximum force, elongation at break, tenacity and work of rupture, are given in Table 1. Viscose, Tencel™ and modal ring spun yarns have a higher maximum force, followed by air-jet and then rotor spun yarns. The difference in the maximum force of tested yarns is the result of yarn spinning techniques that produce different yarn structures. In general, friction forces within the yarns (between the fibres) ensure the resistance of yarn to the applied tensile force. The friction forces between the fibres depend on the number of fibres in the cross-section and the twists of yarns. As the ring, rotor and air-jet yarns



ring spun yarn rotor spun yarn air-jet spun yarn

Figure 2: Tencel™ ring, rotor and air-jet spun yarn images taken with Dino-Lite digital microscope (60× magnification)

Table 1: Yarn tensile properties

Fibre	Spinning process	Tensile properties											
		Breaking force			Breaking elongation			Tenacity			Work of rupture		
		$\bar{X}$ a) (cN)	SD b) (cN)	CV c) (%)	$\bar{X}$ a) (%)	SD b) (%)	CV c) (%)	$\bar{X}$ a) (cN/tex)	SD b) (cN/tex)	CV c) (%)	$\bar{X}$ a) (cNcm)	SD b) (cNcm)	CV c) (%)
Viscose	Ring	347.6	4	1.1	15.2	0.4	2.6	17.4	0.2	1.1	16.8	0.5	2.9
	Rotor	272.7	3	1.1	10.9	0.3	2.7	13.6	0.2	1.1	9.7	0.2	1.9
	Air-jet	313	4.8	1.5	12.4	0.3	2.2	15.6	0.2	1.5	12.1	0.4	3
Tencel™	Ring	551.8	12.7	2.3	10.1	0.1	1.4	27.5	0.6	2.2	16.5	0.5	3
	Rotor	387	4.5	1.2	8.4	0.1	1.5	19.4	0.2	1.2	9.5	0.1	1.6
	Air-jet	403.7	8.5	2.1	8.8	0.2	2.8	20.2	0.4	2.1	10.5	0.4	3.8
Modal	Ring	476.2	8.1	1.7	10.8	0.2	1.5	23.8	0.4	1.7	14.8	0.3	2.1
	Rotor	307.9	5.1	1.7	8.2	0.1	1.6	15.4	0.3	1.7	7.7	0.2	2.7
	Air-jet	415.4	9.4	2.3	9.2	0.2	2.5	20.8	0.5	2.3	11.2	0.4	3.9

a) average, b) standard deviation, b) coefficient of variation are produced with the same count and have approximately the same number of fibres in the cross section, different maximum forces result from different fibre rearrangement and yarn twist. When comparing the same yarn type made of different fibre types, a significant difference in maximum force is apparent. The maximum force difference for ring spun yarns ranges from 13.7% to 58.8%, for rotor spun yarns from 9.1% to 41.9% and for air-jet spun yarns from 2.9% to 29.0%. Therefore, it can be concluded that the greatest difference in maximum yarn strength within the same group of yarn types consisting of different fibres (viscose, Tencel™ and modal) is found in ring spun yarns, followed by rotor spun and finally air-jet spun yarns, where the difference is the smallest. The type of fibres affects the maximum yarn force regardless of the yarn structure; however, depending on the yarn structure, the difference in the maximum force will be greater or smaller (cf. Figure 3).

The yarn elongation within the same yarn type is the highest for viscose, followed by modal and Tencel™ yarns. Regardless of the fibre type, ring spun yarns have the highest elongation, followed by air-jet and rotor spun yarns (cf. Figure 3). The same trend is visible for yarn work of rupture. Ring spun yarns have the highest work of rupture, followed by air-jet and rotor spun yarns. The difference in work of rupture between the same types of viscose, Tencel™ and modal yarns is not significant (cf. Table 1).

The basic knitted fabric parameters are presented in Table 2. The table shows that the parameters

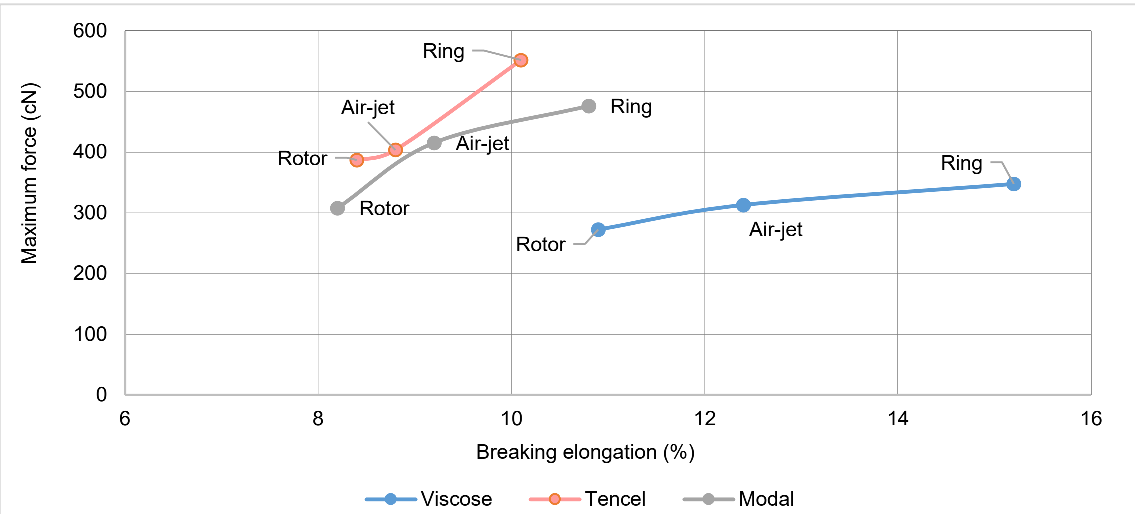


Figure 3: Ring, rotor and air-jet spun yarns F/ε diagram

Table 2: Basic parameters of double jersey knitted fabric

Fibre	Spinning process	D_c a)			D_w b)			T c)			M d) (g/m²)	$L_{u,a}$ e) (1/cm²)	Vm f) (g/cm³)	S g) (%)
		$\bar{X}$ h) (1/cm)	SD i) (1/cm)	CV j) (%)	$\bar{X}$ h) (1/cm)	SD i) (1/cm)	CV j) (%)	$\bar{X}$ h) (mm)	SD i) (mm)	CV j) (%)				
Viscose	Ring	10.9	0.2	1.9	11.8	0.1	1.2	0.63	0.01	1.9	165	257	0.262	39
	Rotor	8.6	0.2	1.8	12	0.1	0.6	0.59	0.01	1.52	131	206	0.222	22
	Air-jet	9	0	0	12	0	0	0.58	0	0.44	127	216	0.219	25
Tencel™	Ring	10.8	0.2	1.6	11.8	0.2	1.5	0.63	0.01	1.64	152	255	0.241	36
	Rotor	9.2	0.2	1.8	12.1	0.1	0.9	0.61	0.01	1.46	128	223	0.21	25
	Air-jet	9	0	0	12.3	0.2	1.7	0.62	0.01	1.17	132	221	0.213	25
modal	Ring	10.3	0.3	2.6	11.8	0.2	1.4	0.58	0.01	1	155	243	0.267	36
	Rotor	9	0	0	12.2	0.2	1.4	0.61	0.01	0.84	128	220	0.21	25
	Air-jet	9.1	0.1	1.3	11.6	0.1	1.1	0.6	0.02	2.76	131	211	0.218	25

a) Loop density in course of fabric, b) loop density in wale of fabric, c) fabric thickness, d) mass per unit area, e) number of loops per unit area, f) knitted fabric volume mass, g) shrinkage in course direction, h) average, i) standard deviation, j) coefficient of variation of knitted fabric structures are influenced by both the yarn types and the raw materials from which the yarns are spun. Mass per unit area (M, g/m^2) is the most significant structure parameter, especially for plain knitted structures. For the analysed unfinished samples of plain double jersey fabrics, the mass per square meter of the knitted fabric ranged from 127 g/m^2 ± 3 g/m^2 to 165 g/m^2 ± 3 g/m^2. The samples knitted with the yarns spun on rotor and air-jet spinning machines have the mass per unit area from 127 g/m^2 ± 3 g/m^2 to 132 g/m^2 ± 4 g/m^2, and statistically speaking, they are not significantly different. The samples knitted with the yarns spun on ring spinning machines have significantly higher mass, ranging from 152 g/m^2 ± 3 g/m^2 to 165 g/m^2 ± 3 g/m^2. The difference of mass per unit area was up to 38 g/m^2 or 23%. This is an important conclusion for the commercial mass production, which leads to the conclusion that it is very complex to produce knitted fabrics with the same yarn counts using different spinning processes. Therefore, it is not recommended to produce the same product in one batch with yarns spun using different spinning processes.

For knitting technologists, it is important to note that fabric mass per unit area is related to the fabric shrinkage in the wale and course direction after the fabric is taken down from the machine and relaxed. The knitted fabric samples with higher mass per unit area had the highest shrinkage (after the removal from the machine and relaxation; from 36% to 39%), while the knitted fabric samples with lower mass per unit area shrank less (from 22% to 25%). On the basis of the above analysis, it can be concluded that the processes of ring, rotor and air-jet spinning lead to substantially different yarn structures, which is manifested in yarn stiffness or flexibility. The rotor and air-jet spinning processes produce stiffer yarn that during knitting forms a larger radius in the stitch curvature, consequently producing wider loops. The wider loop leads to less shrinkage and greater width of the knitted fabric. Table 3 presents the tensile properties of knitted fabrics produced using viscose, Tencel™ and modal ring, rotor and air-jet spun yarns.

The breaking force of the knitted fabric in the wale direction (ranges from 230.9 N to 491.8 N) is on average 3.12 times greater than the breaking force of the fabrics in the course direction (ranges from 70.9 N to 103.8 N). The breaking force of the fabric depends on the breaking force of the yarn used for knitting. The lowest yarn breaking force was achieved with the viscose yarn spun using the rotor spinning process (272.7 cN); therefore, the samples knitted with this yarn had the lowest breaking force (70.9 N). The highest yarns breaking force was achieved with the Tencel™ yarn spun using the conventional ring spinning process (551.8 cN) and the samples knitted with this yarn had the maximum breaking force (103.8 N). Accordingly, the raw material composition of the yarn and the spinning process affect the breaking force of the yarn and thus of the knitted fabric.

The elongation at break is significant for knitted fabrics used to make different underwear and light clothing. In theoretical considerations, knitted fabrics intended for underwear and light clothing have 4 times larger elongation at break in the course direction than in the wale direction, and in this study, it is 5.7 to 7.3 times larger. The reason for higher elongation at break can be found in the yarn structure and the elongation at break of the yarn (ranges from 8.2 to 15.2%). The knitted fabric elongation at break depends on the elongation at break of the yarn, where the elongation at break of the yarn depends on yarn structure and raw material. As with the two previous parameters, the maximum force and elongation at break of the knitted fabric, the work of rupture lies within a wide range and does not exhibit any particular regularity. In some knitted fabrics, they are larger when stretched in the course direction and in some other fabrics, in the wale direction.

By analysing all results of the knitted fabric elongation in the transverse direction, i.e. in the course direction, and in the longitudinal direction, i.e. in the wale direction, the percentages of elastic, elastoplastic and plastic areas were determined. Figure 4 shows the percentages of elastic, elastoplastic and plastic areas in the course direction, and Figure 5 shows the percentages in the wale direction. Values are sorted by the raw material composition and yarn spinning process. The percentages of elastic, elastoplastic and plastic areas in the course direction are the highest for the elastic area ranging from 32% to 55%, followed by the plastic area from 27% to 41%, and the smallest percentages that connect the elastic and plastic area (elastoplastic area) range from 16% to 32%. For the tested knitted samples, these three areas differ significantly in quantity.

Table 3: Double jersey knitted fabric tensile properties

Fibre	Spinning process	Maximum force in knitted fabric course direction (F_c)			Maximum force in knitted fabric wale direction (F_w)			Elongation at break in knitted fabric course direction ($\mathcal{E}_c$)			Elongation at break in knitted fabric wale direction ($\mathcal{E}_w$)		
		$\bar{X}$ [a] (N)	SD [b] (N)	CV [c] (%)	$\bar{X}$ [a] (N)	SD [b] (N)	CV [c] (%)	$\bar{X}$ [a] (%)	SD [b] (%)	CV [c] (%)	$\bar{X}$ [a] (%)	SD [b] (%)	CV [c] (%)
Viscose	Ring	72.8	2.7	3.7	381	9.8	2.3	338.8	33.5	9.9	47.3	1.1	2.3
	Rotor	70.9	2.9	4.2	230.9	13.7	5.9	220.6	9	4.1	33.2	1.4	4.1
	Air-jet	74.4	3.3	4.4	290.2	14.5	5	276.8	5.5	1.9	47.7	1.2	2.5
Tencel™	Ring	103.8	4.8	4.6	491.8	19	3.9	328.2	11.1	3.4	49.3	3.1	6.3
	Rotor	102.2	2.3	2.2	374.7	27.2	7.3	289.7	9.1	3.1	50.3	2.4	4.8
	Air-jet	84.3	5.3	6.3	300.7	16	5.3	266.3	7.8	2.9	46.9	0.9	1.8
Modal	Ring	84.1	3	3.6	392	23.9	6.1	309.5	1.7	0.6	46.5	0.5	1.2
	Rotor	90.8	4.9	5.5	268.4	20.1	7.5	255.4	10.1	3.9	45.2	1.7	3.8
	Air-jet	76.9	2.9	3.8	282.8	20.4	7.2	249.5	8.6	3.5	34.4	0.7	2

[a] average, [b] standard deviation, [b] coefficient of variation

Fibre	Spinning process	Tenacity in knitted fabric course direction (T_c)			Tenacity in knitted fabric wale direction (T_w)			Work of rupture in knitted fabric course direction (W_c)			Work of rupture in knitted fabric course direction (W_w)		
		$\bar{X}$ [a] (cN/mm)	SD [b] (cN/mm)	CV [c] (%)	$\bar{X}$ [a] (cN/mm)	SD [b] (cN/mm)	CV [c] (%)	$\bar{X}$ [a] (cNcm)	SD [b] (cNcm)	CV [c] (%)	$\bar{X}$ [a] (cN cm)	SD [b] (cNcm)	CV [c] (%)
Viscose	Ring	145.6	2.7	3.7	762	9.8	2.6	521.6	101.8	19.5	678	23.8	3.5
	Rotor	141.8	3	4.2	461.8	13.7	5.9	429.5	48.6	11.3	317.9	31.1	9.8
	Air-jet	148.8	3.3	4.4	580.4	14.5	5	461.6	26.3	5.7	472.3	35.8	7.6
Tencel™	Ring	207.6	4.8	4.6	983.6	19	3.9	634.1	49.9	7.9	772.2	79.6	10.3
	Rotor	204.4	2.3	2.2	749.4	27.2	7.3	664.8	42	6.3	570	63.1	11.1
	Air-jet	168.6	5.3	6.3	601.4	16	5.3	464.8	32.8	7.1	438.4	19.5	4.5
Modal	Ring	168.2	3	3.6	784	23.9	6.1	494.1	15.5	3.1	555.1	46.1	8.3
	Rotor	181.6	5	5.5	536.8	20.1	7.5	588	85.5	14.6	382.6	35.9	9.4
	Air-jet	153.8	2.9	3.8	565.6	20.4	7.2	464.6	42.3	9.1	367.7	36.3	9.9

[a] average, [b] standard deviation, [b] coefficient of variation

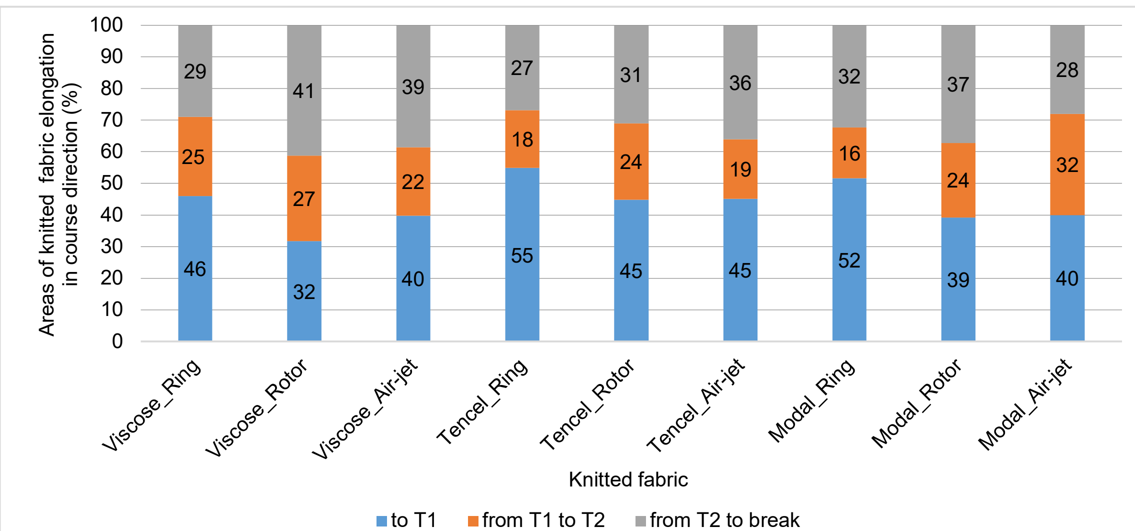


Figure 4: Elastic, elastoplastic and plastic areas of knitted fabric elongation in course direction

The lowest elastic area in the course direction was found for the knitted fabric from viscose rotor yarns (cf. Figure 4). The elastic area was 32% of the total elongation, the elastoplastic area was 41% and the rest of 27% belongs to the area between points T1 and T2 or to the plastic area. The highest elasticity area was found in the sample knitted from the Tencel™ ring spun yarn. The elastic area amounts to 55% in relation to the total elongation, the percentage range between points T1 and T2 (elastoplastic area) is 18% and the percentage of permanent deformation is 27%. It can be seen that the elastic area of knitted fabrics in the course direction is the largest for ring yarns, followed by air-jet and finally rotor spun yarns, regardless of the raw material. The yarn raw material affects the elastic area of knitted fabrics consisting of different yarn structures. The greatest reduction in the knitted fabric elastic area is visible between the viscose ring and rotor spun yarns (reduction of 30%). The reduction in the elastic area of the knitted fabric in the case of viscose air-jet yarns is only by 13% lower when viscose ring yarns are taken into account. Taking Tencel™ ring spun yarns into account, the elastic area reduction for knitted fabrics with Tencel™ rotor and air-jet spun yarns is the same or 18% lower. Elastic area for knitted fabrics made from modal yarns of different yarn structures are 23% less elastic for air-jet and 25% less for rotor yarns compared to ring spun yarns. On the other hand, the elastoplastic area of the knitted fabric is the smallest for ring spun yarns, regardless of the raw material of spun yarns.

When testing the tensile properties of the knitted fabric in the wale direction, individual areas are quite different from those in the course direction due to different stitch directions. The share of the elastic area is represented by a percentage range from 15% to 26%, the plastic deformation from 49% to 70%, and the share from the end of elasticity to the beginning of plastic deformation (elastoplastic area) from 15% to 27% (cf. Figure 5). The diagram (cf. Figure 5) shows that the smallest elastic area in the wale direction was measured for the knitted fabric knitted from viscose rotor spun yarns and was the same as in the course direction. The elastic area was 15% of the total elongation, the elastoplastic areas was 15% and the share of permanent deformation was 70%. The largest elastic area was found for the sample of the knitted fabric knitted from the modal ring spun yarn. The elastic area was 26% relative to the total elongation, the elastoplastic area was 27% and the plastic area was 51%. Nevertheless, there is no trend in elastoplastic areas with regard to the yarn type and raw material as there is in the course direction.

4 Conclusion

The fineness and the twist of yarns are uniform with a low coefficient of variation, which indicates high quality yarns. The difference in the tensile properties of tested yarns is the result of yarn spinning techniques that produce different yarn structures.

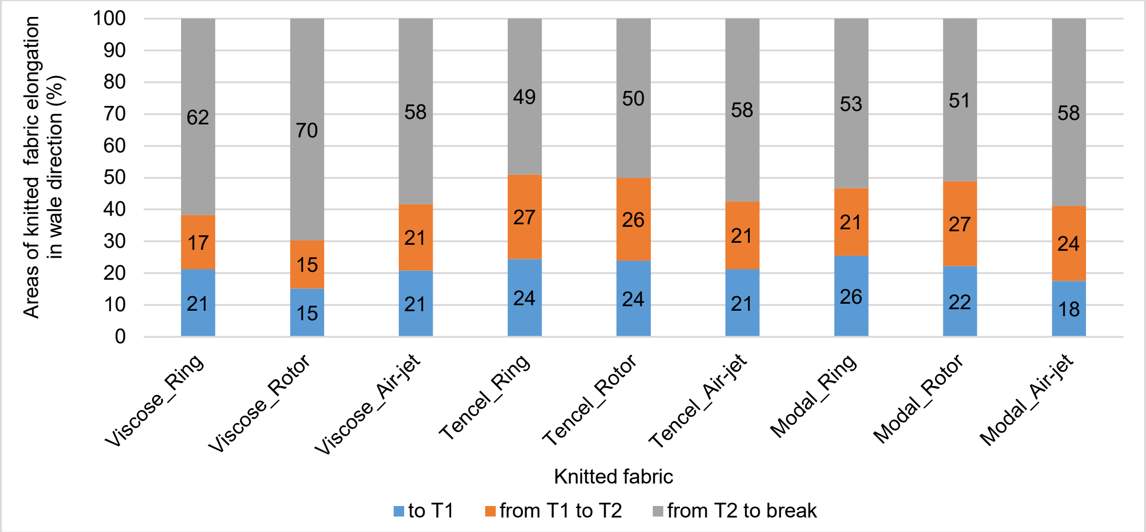


Figure 5: Elastic, elastoplastic and plastic areas of knitted fabric elongation in wale direction

The type of fibres (viscose, Tencel™ and modal) influences the maximum yarn strength regardless of the yarn structure; however, depending on the yarn structure, the difference in maximum force will be greater or smaller. Ring spun yarns have the greatest elongation followed by air-jet and rotor spun yarns, regardless of the fibre type. The fabrics were knitted using the same machine parameters, and the results show that the knitted structures are influenced by both the yarn types and the raw materials from which the yarns were spun. The difference in mass per unit area, one of the most important parameters of the knitted structure, was up to 38 g/m^2 or 23%. This is an important factor for the commercial mass production, which leads to the conclusion that it is very complex to produce knitted fabrics in one batch with the same yarn counts spun using different spinning processes. Knitted fabrics made of ring spun yarns have much higher mass (up to 38 g/m^2) compared to knitted fabrics made of rotor and air-jet spun yarns. The knitted samples with higher mass per unit area had the highest shrinkage after the removal from the machine and relaxation, which leads to the conclusion that the processes of ring, rotor and air-jet spinning produce substantially different yarn structures manifested in stiffness where stiffer yarn during knitting forms a larger radius in the stitch curvature, consequently forming wider loops. Wider loops result in less shrinkage and greater width of the knitted fabric.

The percentages of elastic, elastoplastic and plastic areas in the course direction are the highest for the elastic area ranging from 32% to 55%, followed by the plastic area from 27% to 41%, and the lowest percentages connecting the elastic and plastic area (elastoplastic area) range from 16% to 32%. When testing the tensile properties of the knitted fabric in the wale direction, individual areas are quite different due to different loop directions. The share of the elastic area is represented by a percentage range from 15% to 26%, plastic deformation from 49% to 70% and the percentage of the elastoplastic area from 15% to 27%. For the tested knitted samples, these three areas differ significantly in amount, both in the course and wale direction.

The elastic area of knitted fabrics in the course direction is the highest in ring spun yarns, followed by air-jet and finally rotor spun yarns, regardless of the raw material. The yarn raw material affects the elastic area of knitted fabrics consisting of different yarn structures. The greatest reduction in the knitted fabric elastic area is visible between viscose ring and rotor spun yarns (reduction of 30%). On the other hand, the elastoplastic area of the knitted fabric is the smallest for ring spun yarns, regardless of the raw material of the spun yarn. In the elastoplastic areas of the knitted fabric, there is no visible trend in the yarn type and raw material in the wale direction as in the course direction.

Acknowledgements

This work was fully supported by the Croatian Science Foundation under the project IP-2016-06-5278.

References

1. LAWRENCE, Carl. *Advances in yarn spinning technology*. Cambridge : Woodhead Publishing, 2010.
2. SARIOGLU, Esi., ÇELIK, Nihat. Investigation on regenerated cellulosic knitted fabric performance by using silicone softeners with different particle sizes. *Fibres & Textiles in Eastern Europe*, 2015, **113**(5), 71–77, doi: 10.5604/12303666.1161760.
3. PETERSON, Joel, ECKARD, Alexandra, Hjelm Josefine, Morikawa Hideaki. Mechanical-property-based comparison of paper yarn with cotton, viscose, and polyester yarns. *Journal of Natural Fibers*, 2021, **18**(4), 492–501, doi: 10.1080/15440478.2019.1629372.
4. Berihun Sitotaw, Dereje, Fentahun Adamu, Biruk. Tensile properties of single jersey and 1×1 rib knitted fabrics made from 100% cotton and cotton/lycra yarns. *Journal of Engineering*, 2017, 2017(4310782), 1–7, doi: 10.1155/2017/4310782.
5. Omeroglu, Sunay, Ulku, Sukriye. An investigation about tensile strength, pilling and abrasion properties of woven fabrics made from conventional and compact ring-spun yarns. *Fibres & Textiles in Eastern Europe*, 2007, **15**(1), 39–42.
6. Suzuki, Yukihiro, Sukigara, Sachiko. Mechanical and tactile properties of plain knitted fabrics produced from rayon Vortex yarns. *Textile Research Journal,* 2013, **83**(7) 740–751, doi: 10.1177/0040517512467132.
7. Pavlović, Željka, Vrljičak, Zlatko. Comparing double jersey knitted fabrics made of Tencel and modal yarns, spun by different spinning methods.

Journal of Engineered Fibers and Fabrics, 2020, **15**, 1–15, doi: 10.1177/1558925020919854.

8. De Araujo, Maico D, Smith, Gregor W. Spirality of knitted fabrics: Part II: the effect of yarn spinning technology on spirality. *Textile Research Journal*, 1989, **59**(6), 350–356, doi: 10.1177/004051758905900607.
9. Sakthiveli, Jallipatty Chinnasamy, Anbumani N. Dimensional properties of single jersey knitted fabric made from new and regenerated cellulosic fibres. *Journal of Textile and Apparel, Technology and Management*. 2012, **7**(3), 1–10.
10. Penava, Željko, Simic Penava, Diana, Milos, Lozo. Experimental and analytical analyses of the knitted fabric off-axes tensile test. *Textile Research Journal,* **91**(1-2), 62–72, doi: 10.1177/0040517520933701.
11. Skenderi, Zenun, Kopitar, Dragana, Ercegović Ražić, Sanja, Iveković, Goran. Study on physical-mechanical parameters of ring-, rotor- and air-jet-spun modal and micro modal yarns. *Tekstilec*, 2019, **62**(1), 42–53, doi: 10.14502/Tekstilec2019.62.42-53.

Mykola Riabchykov, Alexandr Alexandrov, Roman Trishch, Anastasiia Nikulina, Natalia Korolyova
Ukrainian Engineering Pedagogics Academy, Universitetska street, 16, Kharkiv, Ukraine

Prospects for the Development of Smart Clothing with the Use of Textile Materials with Magnetic Properties

Možnosti za razvoj pametnih oblačil z uporabo tekstilnih materialov z magnetnimi lastnostmi

Original scientific article/*Izvirni znanstveni članek*

Received/*Prispelo* 5-2021 • Accepted/*Sprejeto* 12-2021

Corresponding author/*Korespondenčni avtor:*
Prof. Mykola Riabchykov, PhD
E-mail: nikolryab@uipa.edu.ua
Phone: +30988404276
ORCID ID: 0000-0002-9382-7562

Abstract
The article studies the properties of textile materials filled with magnetite nanoparticles. These materials have great prospects for creating smart clothes. They have both magnetic and hygienic properties. Chemical transformations in the production of magnetic nanopowder are described. The end product of the process is a mixture of oxides of divalent and ferric iron. The resulting mixture has magnetic properties. Conducted micro and macro experiments showed sufficient adhesion retention strength of magnetite nanoparticles in a textile material. Microscopic studies of the attachment of magnetic particles to the fibers of a textile material have been conducted. The data obtained in express mode allow us to determine the average mass of a magnetic particle in a textile material, the total number of nanoparticles, and, accordingly, to predict the magnetic force that a textile material saturated with magnetite can possess. The existence of the magnetic properties of a textile material filled with magnetite nanoparticles has been proven. A mathematical model of the dependence of the magnetic attraction force of a textile material on the distance and the number of abrasion cycles has been developed. The directions of the use of magnetic textile materials for the creation of smart clothes are proposed. Potential uses for such materials include sportswear and textiles for the disabled. The developed methods can predict the magnetic strength of the obtained textile materials and evaluate their resistance, which is necessary in the development of smart clothing elements based on these materials.
Keywords: textile materials, nanotechnology, magnetite, smart clothes, magnetic force

Izvleček
Članek je posvečen študiji lastnosti tekstilnih materialov, funkcionaliziranih z nanodelci magnetita, ki izkazujejo velik potencial za izdelavo pametnih oblačil. Odlikujejo jih magnetne in higienske lastnosti. Opisane so kemične pretvorbe pri proizvodnji nanodelcev magnetita v prahasti obliki. Končni produkt postopka je zmes oksidov dvovalentnega in trivalentnega železa. Nastala zmes ima magnetne lastnosti. Rezultati izvedenih analiznih metod so pokazali zadostno adhezijo magnetitnih nanodelcev v tekstilnem materialu. Opravljena je bila mikroskopska analiza magnetnih delcev na vlaknih tekstilnega materiala. Pridobljeni podatki omogočajo določitev povprečne mase magnetnih delcev v tekstilnem materialu, skupnega števila nanodelcev in posledično napoved magnetne sile, ki jo lahko ima tekstilni material, funkcionaliziran z magnetitom. Dokazan je bil obstoj magnetnih lastnosti funkcionaliziranega tekstilnega

materiala. Razvit je bil matematični model odvisnosti magnetne privlačne sile tekstilnega materiala od razdalje in števila ciklov drgnjenja. Predlagane so usmeritve za uporabo magnetnih tekstilnih materialov za izdelavo pametnih oblačil. Potencialne uporabe takšnih materialov so športna oblačila in tekstil za invalide. Z razvitimi metodami lahko predvidimo magnetno moč proizvedenih tekstilnih materialov in ocenimo njihovo obstojnost, kar je potrebno pri razvoju pametnih oblačil, ki temeljijo na teh materialih.
Ključne besede: tekstilni material, nanotehnologija, magnetit, pametna oblačila, magnetna sila

1 Introduction

The trend of developing and creating smart clothes and smart materials is quite pronounced across the world. In some cases, the development of such clothing is based on traditional textile materials. At the same time, materials with new properties that allow you to create clothes of a new level constantly appear in the world. In [1], fabrics with the properties of electrical conductivity are considered, and in [2], materials with controlled thermal conductivity are developed.

In many cases, the creation of new textile smart materials is associated with modern nanotechnology. Articles [3, 4] substantiate the active development of textile materials using innovative nanotechnologies both in the production of such materials and in the direction of their finishing.

A large place is occupied by metal nanoparticles, which give the materials various properties in the process of creating textile materials with new properties. In [5], zinc oxide nanoparticles were proposed to be used as chemical protective materials, while the efficiency was recognized as being quite high during photocatalytic degradation.

The article [6] states that homogeneous nanoparticles of TiO_2 and SiO_2 can be useful for developing methods of protection against ultraviolet radiation for various substrates, including textile ones.

One of the applications of such materials is to protect against ultraviolet radiation, which has a negative effect on the human body [7]. The work [8] shows the process of metallizing textile materials with metal nanoparticles in order to protect a person from electromagnetic radiation.

A series of data indicates that the filling of textile materials with nanoparticles has a significant antimicrobial effect. According to various data, such an effect can be exerted by silver and copper nanoparticles upon their modification of textile fibers [9]. Also, the results on the deposition of zinc dioxide nanoparticles for antimicrobial finishing of cotton fabric [10] are known.

The article [11] shows the use of metallic nanomaterials in imparting antimicrobial properties to textiles. Adhesive and protective properties were investigated. The test results showed that the nanoparticle coated fibers had high antibacterial activity.

A number of studies consider the use of magnetite nanoparticles [12], which in addition to magnetic and protective properties, also have bacteriostatic properties [13] as a prospect.

The introduction of such materials into modern smart technologies is hampered by the absence of regularities in their properties, which, in turn, is constrained by the complexity of micro-researching nanomaterials. In [14–15], express methods for studying nanomaterials based on mathematical modeling of their dispersion are substantiated.

The aim of this work is to substantiate the laws of magnetic properties in textile materials containing magnetite nanoparticles based on statistical micrometric studies through the process of modeling the real magnetite content in textile fibers.

The obtained results will allow us to develop smart materials with new qualities, which, in addition to the properties of antimicrobial and electromagnetic protection, will have magnetic qualities which will significantly expand the scope of their application [16–17].

2 Methodology

The device is based on a glass reactor for the synthesis of substances 1 (Figure 1). Above the reactor (1) filled with solution (2), an asynchronous motor (4) is fixed and a glass mixer (3) is connected to it. Given the low mechanical properties of the mixer and the need to prevent unwanted vibrations, the mixer passes through an additional bearing (5). The speed of the motor is regulated by a transformer.

The process is carried out in a chemical cabinet with the suction of unwanted substances. Aqueous mixtures of ferrous sulfate and ferric chloride are mixed in the reactor.

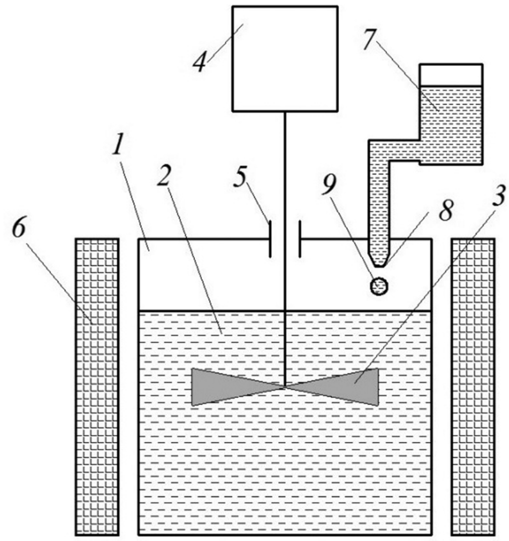


Figure 1: Device for mixing the solution for the preparation of magnetite

Legend: 1 – reactor 2 – solution 3 – glass mixer 4 – asynchronous motor 5 – bearing 6 – thermal insulator 7 – solution of ammonia 8 – dispenser 9 – drops of ammonia

The reactor is covered by a thermal insulator. Above the reactor, a vessel with a solution of ammonia (7) is situated. Through the dispenser (8), the liquid is fed in drops (9) into the reactor hole.

Continuous stirring is performed. Samples are constantly taken until an alkaline environment is achieved.

The reactions that occur can be represented as:

$$FeSO_4 + 2\ NH_4OH \rightarrow FeO + (NH_4)_2SO_4 \quad \text{(I)}$$

$$FeCl_3 + NH_4OH \rightarrow Fe(OH)_3 + (NH_4)_3Cl \quad \text{(II)}$$

$$2\ Fe(OH)_3 \rightarrow Fe_2O_3 + H_2O \quad \text{(III).}$$

The finished product of our process is a mixture of oxides of ferrous and trivalent iron. The resulting mixture has magnetic properties. Raising a magnet to the vessel forms a characteristic profile of the location of the particles (Figure 2). The most probable reason for the curvature of the distribution profile is the different particle size. According to our hypothesis, the deviation of the profile from the line shows the deviation of particle sizes from the mean value. The resulting distribution is almost normal.

The final product was obtained using a device for vacuum filtration (Figure 3). This device consisted of a vacuum pump (1), a Bunsen flask (2) and a Buchner funnel (3).

Figure 2: Demonstration of magnetic properties of magnetite nanoparticles

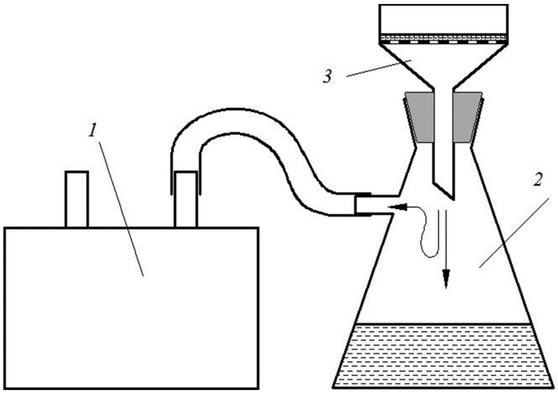


Figure 3: Device for vacuum filtration of magnetite

Legend: 1 – vacuum pump 2 – Bunsen flask 3 – Buchner funnel

Magnetite was applied to the fabric surface as a suspension of nano powder with a Fe_3O_4 content of 43% stabilized potassium oleate. After application to the material, the samples were squeezed, rinsed in cold water and dried. The strength of the nanopowder in the fibers of the material was checked by conducting abrasion tests of the samples and microscopic studies of the microfibers of the material were conducted.

3 Results and discussion

Magnetite impregnation of cotton textile material results in the appearance of magnetic properties.

Micrometric studies of cotton fibers impregnated with magnetite nanoparticles demonstrate a rather complex distribution of particles over the fibers (Figure 2). At the same time, significant adhesion of particles to fibers is observed. Unfortunately, an optical microscope under the conditions of rapid experiments does not make it possible to identify magnetite particles in the nanoscale range.

At the same time, these conditions make it possible to identify the initial branch of the particle size distribution curve. Based on the assumptions given in [15], the distribution of the dimensions of magnetic particles can be described by the equation 1 and a graph, shown in Figure 3:

$$f(d) = \frac{\alpha}{\beta^{\alpha}} d^{\alpha-1} e^{-\left(\frac{d}{\beta}\right)^{\alpha}} \quad (1),$$

where d is the dimension of a magnetic particle, a and b are constants that show the dispersion intensity of nanoparticles.

In this case, the difference between Smik and Smax shows the area available for observation in an optical microscope. The obtained data in the microsize range (Figure 2) allow the prediction of the size distribution according to the method described in the article [15].

The data obtained in express mode allow us to determine the average mass of a magnetic particle in a textile material, the total number of nanoparticles, and, accordingly, to predict the magnetic force that a textile material saturated with magnetite can possess. Unfortunately, most of the magnetite particles deposited on the textile material have nanoscale and are not available for direct observation. Meanwhile, the technique described in [15] makes it possible to determine the real distribution based on the analysis of measurements in the optical range. In this case, the proportion of nanoparticles that fall into different size ranges, determined by the method of [15] is given in Table 1.

To reveal the magnetic properties of the obtained textile materials, an installation was used (Figure 4), in which a sample with a magnetic textile material (1) is located. The instrument is based on an electronic balance (2). The sample (1) is separated from the balance

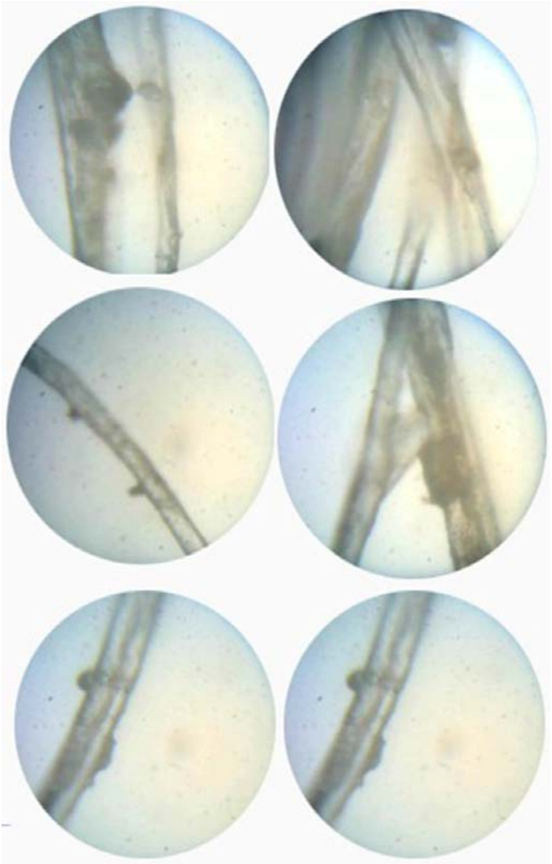


Figure 4: Cotton fabric fibers with magnetite microparticles

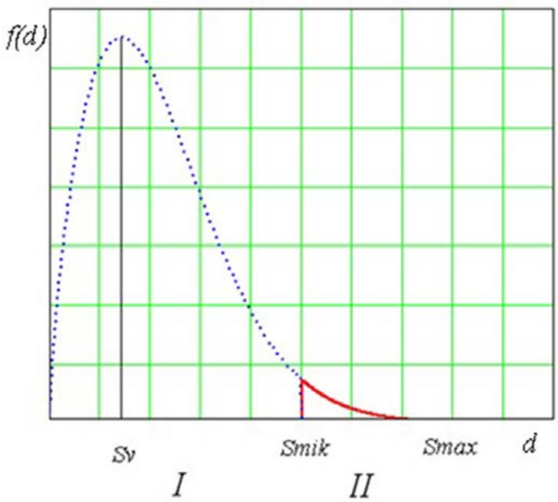


Figure 5: The distribution of magnetite particles on the fibers of a textile material

Table 1: Particle size distribution

Particle size (nm)	0–30	30–60	60–90	90–120	120–150	150–180
Relative number	0.18	0.26	0.21	0.15	0.1	0.04

using a magnetic insulator (3) to prevent the influence of magnetic fields on the balance readings. A permanent magnet (4) is fixed on the rack (5) above the balance. This device has the ability to change the distance between the magnet and the material *x*. The difference between the readings of the balance in a magnetic field and without it shows the magnetic force that acts on the textile material.

For the experiment, a sample of cotton material was taken with a surface density of 60–90 g/m^2 with a size of 10 × 10 cm (Figure 6).

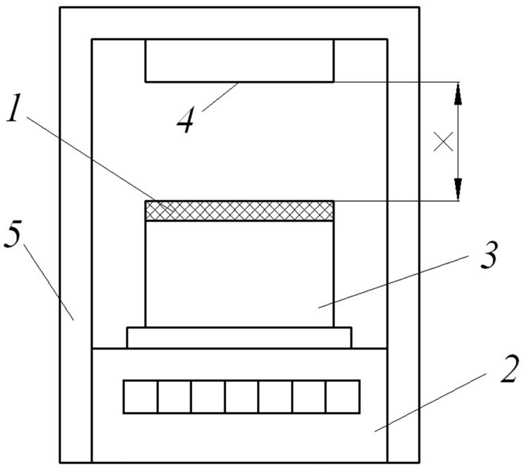


Figure 6: Measuring the force of magnetic attraction

Legend: 1 – textile material 2 – electronic balance 3 – magnetic insulator 4 – permanent magnet 5 – rack

Experiments with different saturations of textile material with magnetite nanoparticles were conducted. The distance from the magnet, as well as the content of nanoparticles in the material were changed. In addition, the retention resistance of the nanoparticles in the textile material was measured. In this case, the material with deposited magnetite was subjected to cyclic abrasion, after which the magnetic attraction force was measured.

Let us analyze the graph in Figure 7. When the magnet is removed from the material, the graph asymptotically approaches zero. The exponential function (equation 2)

$$f(x) = a \cdot e^{-b\left(\frac{h-x}{h}\right)} \tag{2}$$

where *a* is the force corresponding to the weight of the sample, *b* is the intensity of the decrease in force with distance from the magnet, *h* is the distance to the magnet at which the force of attraction corresponds to the weight of the sample.

In this function, the value of h determines the distance to the magnet at which the force of attraction corresponds to the weight of the sample (the material ceases to be a separate sample and sticks to the magnet), the value of b determines the intensity of the decrease, the value of a determines the value of the function. The value of h below the exponent in the denominator is entered to ensure that the argument is dimensionless.

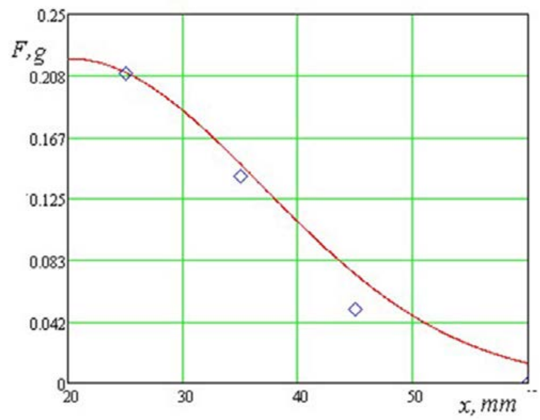


Figure 7: Changing the magnetic force of a textile sample from a distance

At zero value of x-h, the maximum force of attraction of the textile material to the magnet is observed. The behavior of the function demonstrates the extremum. Such behavior cannot be described by a simple exponent. To ensure this behavior, it is proposed to exponentiate the argument below the exponent. Then, the function will take the form of equation 3.

$$F = a \cdot e^{-b\left(\frac{x-h}{h}\right)^2} \tag{3}$$

where *F* is force of attraction of textile material to the magnet.

To check the existence of an extremum, you can determine the derivative (equation 4).

$$\frac{dF}{dx} = -2 \cdot a \cdot b \frac{x-h}{h^2} e^{-b\left(\frac{x-h}{h}\right)^2} \tag{4}$$

This derivative is zero for x = h. This corresponds to the condition of Figure 7.

The conducted studies of the magnetic properties showed the dependence on the saturation of the tissue with magnetite particles, the distance to the magnet, the number of cycles of friction between the tissue and the nanoparticles. The measurement results are shown in Figure 4.
The data in Figure 2 can be approximated by dependence (equation 4).

$$F = 0{,}23 \cdot e^{-0{,}74\left(\frac{x-20}{20}\right)^2} \tag{4}$$

Tests were carried out with the abrasion of a textile sample after ten, thirty and one hundred abrasions. It was shown that in the general case the magnetic force is determined by equation 5.

$$F = a \cdot e^{-b\left(\frac{x-20}{20}\right)^2} \tag{5}$$

The values included in this expression can be found from the experimental dependences in Figure 5.

As a result, the dependence of the magnetic force on the number of abrasions can be determined by the expression (6).

$$F = 0{,}115 \cdot \left(1 + e^{-\frac{n}{30}}\right) \cdot e^{-\left[0{,}74+0{,}19\cdot\left(1-e^{-\frac{n}{25}}\right)\right]\left(\frac{x-20}{20}\right)^2} \tag{6}$$

This value of the force of attraction to the magnet can be used in the process of designing special clothing.

In previous publications [16], we proved the bacteriostatic properties of textile materials filled with nanoparticles. In this work [18], directions for creating smart clothes based on metamaterials are proposed. The existing proposals for the development of smart clothes [19] do not provide for the active influence of clothes on a person. The use of magnetic textile materials based on magnetite nanoparticles makes it possible to create smart clothes with active action.

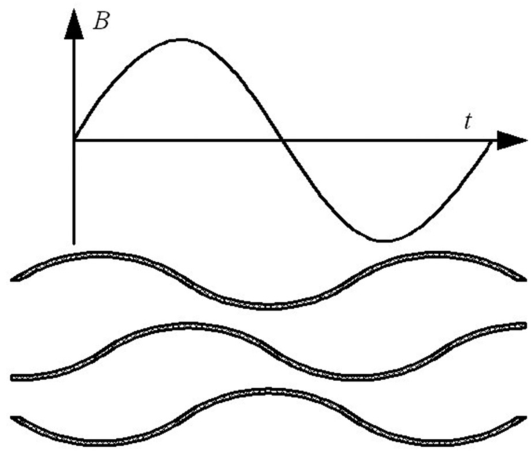


Figure 9: Movement of a magnetic textile material in an alternating magnetic field

In the case of an alternating magnetic field, the magnetic textile material acquires the ability to move in a controlled manner (Figure 9). This dynamic allows for a massaging or other movement to provide comfort, which can be beneficial for athletes [20] or sick people. Application of magnetic nanomaterials to the surface of pile materials are shown in Figure 10.

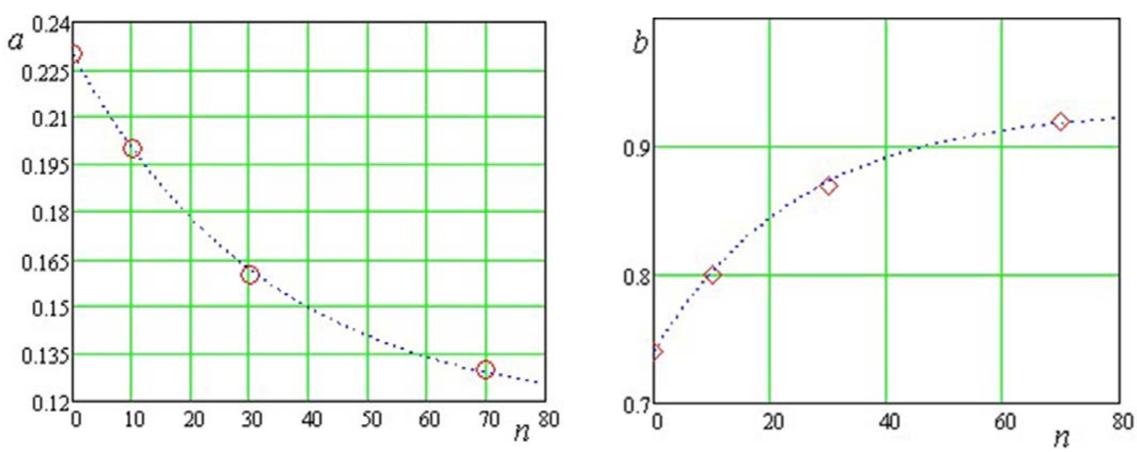


Figure 8: Parameter “a” and “b” change based on the number of abrasions

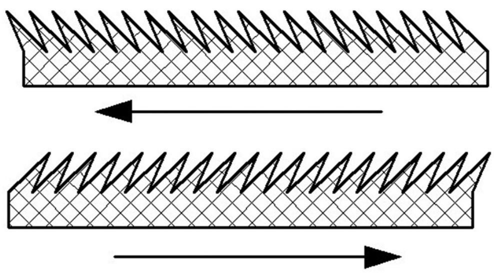


Figure 10: Magnetic pile materials in an alternating magnetic field

In the case of using pile magnetic materials, it becomes possible to localize the body in an arbitrary place to create a treatment effect or comfort.

4 Conclusion

Textile material filled with nanoparticles of magnetite has great prospects for creating smart clothes. The resulting materials, in addition to magnetic properties, have a hygienic and disinfecting effect. A mixture of oxides of ferrous and ferric iron in the form of nanoparticles has good adhesion to the fibers of the textile material. An express method for predicting the statistical distribution of magnetite nanoparticles in a textile material based on observation data is proposed. The developed methods can predict the magnetic strength of the obtained textile materials and evaluate their resistance, which is necessary when developing smart clothing elements based on these materials.

According to our observations, the mechanical properties of the textile material changed insignificantly after the application of magnetic nanopowder. The resistance to retention of magnetic nanoparticles increases significantly over time and after 2–3 days abrasion is almost not observed. We believe that the kinetics of changes in the retention resistance of nanoparticles in a textile material requires further study.

In addition, our preliminary studies described in [17] demonstrate the bacteriostatic properties of magnetic textiles, which will further prove the rationality of its use in smart clothing.

References

1. BARABÁŠ, J., BALOGOVÁ, Ľ., GÁLA, M., BABUŠIAK, B. Conductive paths and influence of theirinterconnection on tranmission of electric signal in smart clothing. *Vlákna a textil*, **24**(4), 2017, 9–14.
2. ROGALE FIRŠT, Snježana, ROGALE, Dubravko, NIKOLIĆ, Gojko Intelligent clothing: first and second generation clothing with adaptive thermal insulation properties. *Textile Research Journal,* 2018, 88(9), 2214–2233, doi: 10.1177/0040517517718190.
3. MAGNI, A. Nanotechnologies and the textile industry: the future is upon us. *Tinctoria*, 2004, **101**(10), 60–61.
4. YEZHOVA, O.V. Prognosing development of textile nanotechnologies. *Vlákna a textil*, 2017, **24**(4), 66–69.
5. HAN, Y., OBENDORF, S.K. Reactivity and reusability of immobilized zinc oxide nanoparticles in fibers on methyl parathion decontamination. *Textile Research Journal*, 2016, **86**(4), 339–349, doi: 10.1177/0040517515596935.
6. ZHANG, M., XIE, W., TANG, B., SUN, L., WANG, X. Synthesis of TiO_2&SiO_2 nanoparticles as efficient UV absorbers and their application on wool. *Textile Research Journal*, 2017, **87**(14), 1784–1792, doi: 10.1177/0040517516659375.
7. VLASENKO, V., SMERTENKO, P., BEREZNENKO, S., ARABULI, S. Synthesis of metals nano-particles in the porous structure of textiles for UV-shielding. *Vlákna a textil*, 2017, **24**(4), 30–33.
8. DIACHOK, T., BEREZNENKO, S., YAKYMCHUK, D., ALEKSANDROV, M. Development of equipment for complex man protection from artificial non-ionizing EMR. *Vlákna a textile*, 2019, **26**(2), 9–13.
9. GUTAROWSKA, B., STAWSKI, D., SKÓRA, J., HERCZYŃSKA, L., PIELECH-PRZYBYLSKA, K. PLA nonwovens modified with poly(dimethylaminoethyl methacrylate) as antimicrobial filter materials for workplaces. *Textile Research Journal*, 2015, **85**(10), 1083–1094, doi: 10.1177/0040517514559581.
10. KAR, T.R., SAMANTA, A.K., SAJID, M., KAWARE, R. UV protection and antimicrobial finish on cotton khadi fabric using a mixture of nanoparticles of zinc oxide and poly-hydroxy-amino methyl silicone. *Textile*

Research Journal, 2019, **89**(11), 2260–2278, doi: 10.1177/0040517518790973.

11. XU, S., ZHANG, F., SONG, J., KISHIMOTO, Y., MORIKAWA, H. Preparation of silver nanoparticle-coated calcium alginate fibers by hyperbranched poly(amidoamine)-mediated assembly and their antibacterial activity. *Textile Research Journal*, 2015, **86**(8), 878–886, doi: 10.1177/0040517515599745.
12. BOGREN, S., FORNARA, A., LUDWIG, F., DEL PUERTO MORALES, M., STEINHOFF, U., HANSEN, M.F., KAZAKOVA, O., JOHANSSON, C. Classification of magnetic nanoparticle systems - synthesis, standardization and analysis methods in the NanoMag project. *International Journal of Molecular Sciences*, 2015, **16**(9), 20308–20325, doi: 10.3390/ijms160920308.
13. TSYKHANOVSKA, I., YEVLASH, V., ALEXANDROV, A., KHAMITOVA, B., SVIDLO, K., NECHUIVITER, O. Forming the structure of whipped desserts when introducing the food additive "Magnetofood" to their formulation. *Eastern-European Journal of Enterprise Technologies,* 2019, **2**(11(98)), 45–55, doi:10.15587/1729-4061.2019.161855.
14. RODGERS, J., ZUMBA, J., FORTIER, C. Measurement comparison of cotton fiber micronaire and its components by portable near infrared spectroscopy instruments. *Textile Research Journal*, 2017, **87**(1), 57–69, doi: 10.1177/0040517515622153.
15. RIABCHYKOV, M., ALEXANDROV, A., TSYKHANOVSKA, I., NECHIPOR, S., NIKULINA, A., VILKOV, S. Distribution of the sizes of microcapsules in two-phase emulsions for treatment of textile materials. *Vlákna a textile*, 2019, **26**(4), 47–52.
16. LIU, S., TONG, J., YANG, C., LI, L. Smart e-textile: resistance properties of conductive knitted fabric - single pique. *Textile Research Journal*, 2017, **87**(14), 1669–1684, doi: 10.1177/0040517516658509.
17. RIABCHYKOV, M., ALEXANDROV, A., SYCHOV, Y., NIKULINA, A. Bacteriostatic properties of medical textiles treated with nanomaterials based on Fe_2O_3. *IOP Conference Series: Materials Science and Engineering,* 2021, **1031**(1), 1–6, doi:10.1088/1757-899x/1031/1/012036.
18. MORADI, B., FERNÁNDEZ-GARCÍA, R., GIL, I. Effect of smart textile metamaterials on electromagnetic performance for wireless body area network systems. *Textile Research Journal*, 2019, **89**(14), 2892–2899, doi: 10.1177/0040517518803786.
19. PÉREZ-VILLACASTÍN, Julián, GAETA, Eugenio. Smart clothes to take care of people or smart people who use clothes to take care of themselves? *Revista Española de Cardiología*, 2015, **68**(7), 559–561, doi: 10.1016/j.rec.2015.03.009.
20. SCATAGLINI, S., MOORHEAD, A.P., FELETTI, F. A systematic review of smart clothing in sports: possible applications to extreme sports. *Muscles, Ligaments and Tendons Journal*, 2020, **10**(2), 333–342.

Upama Nasrin Haq[1], Tania Akhter Ite[2]
[1] Bangladesh University of Textiles (BUTEX), Faculty of Fashion Design and Apparel Engineering, Department of Apparel Engineering, Tejgaon, Dhaka, Bangladesh
[2] Simon Fraser University, MA in Economics, Burnaby, British Columbia, Canada

Exploratory Study of Textile Undergraduates' Knowledge and Perception towards Eco-Friendly Clothing in Bangladesh

Raziskovalna študija znanja in zaznavanja okolju prijaznih oblačil dodiplomskih študentov tekstilstva v Bangladešu

Original scientific article/*Izvirni znanstveni članek*
Received/*Prispelo* 9-2021 • Accepted/*Sprejeto* 11-2021

Corresponding author/*Korespondenčna avtorica:*
Upama Nasrin Haq, Assist Prof
E-mail: upamahaq@butex.edu.bd
Phone: +8801792795686
ORCID ID: 0000-0003-4114-8557

Abstract

Environmentalism leads to the concept of eco-friendly clothing (EFC) and its popularity is advancing all over the world. In-depth knowledge acquisition regarding EFC has become a fundamental requirement for Bangladeshi Textile undergraduates as they are the future professionals in the EFC sector. To ascertain the knowledge level and perception of the Bangladeshi textile undergraduates regarding EFC was the aim of this study. In this exploratory study, a self-administered questionnaire was used to collect data through purposive sampling from the students enrolled into the Bangladesh undergraduate Textile Engineering programme. The respondents were 282 students of the fourth year of different universities located in Dhaka city. Descriptive statistics were used to represent the findings of the research. The results showed that 82.3% of the respondents were informed about EFC, 35.8% were knowledgeable regarding EFC raw materials and 53.02% were cognisant about the production process. 89.4% of the respondents expected one particular course on EFC in curriculum and 94% wanted to contribute towards EFC in the future. The study revealed that undergraduates have a knowledge gap regarding EFC, while their willingness to learn and contribute is very optimistic. The findings suggested that the evaluation and modification of the curriculum for EFC and incorporation of EFC courses can lessen this salient gap.
Keywords: eco-friendly clothing, textile undergraduate, knowledge, perception, curriculum

Izvleček

Okoljevarstvo vodi do koncepta Okolju prijaznih oblačil, s katerim se srečujemo po vsem svetu. Poglobljeno pridobivanje znanja o okolju prijaznih oblačilih je postalo temeljna zahteva dodiplomskega študija tekstilstva v Bangladešu, katerega študenti so bodoči strokovnjaki v oblačilnem sektorju. Glavni cilj študije je bil ugotoviti raven znanja in zaznavanja okolju prijaznih oblačil dodiplomskih študentov tekstilstva v Bangladešu. V raziskovalni študiji je bil uporabljen vprašalnik za zbiranje podatkov s pomočjo namenskega vzorčenja študentov, vpisanih v bangladeški dodiplomski študijski program tekstilnega inženirstva. Anketiranih je bili dvesto dvainosemdeset študentov četrtega letnika z različnih univerz v Daki. Za prikaz ugotovitev raziskave je bila uporabljena deskriptivna statistika. Rezultati so pokazali, da je 82,3 odstotka

anketirancev seznanjenih z okolju prijaznimi oblačili, 35,8 odstotka jih je bilo seznanjenih s surovinami za izdelavo okolju prijaznih oblačil in 53,02 odstotka s proizvodnim procesom tovrstnih oblačil. Kar 89,4 odstotka anketirancev je pričakovalo poseben predmet o okolju prijaznih oblačilih v predmetniku, 94 odstotkov pa jih želi prispevati svoj delež k izdelavi okolju prijaznih oblačil v prihodnosti. Študija je pokazala, da imajo dodiplomski študenti vrzel v znanju o okolju prijaznih oblačilih, medtem ko sta njihova pripravljenost za učenje in prispevek k izdelavi tovrstnih oblačil zelo optimistična. Ugotovitve kažejo, da lahko vrednotenje in sprememba predmetnika ter vključitev predmetov o okolju prijaznih oblačilih zmanjšajo ugotovljeno izrazito vrzel.
Ključne besede: okolju prijazna oblačila, dodiplomski študij tekstilstva, znanje, zaznavanje, učni načrt

1 Introduction

Clothing industries have both social and environmental negative externalities [1, 2], whereas the environmental loss is the most significant among all other magnitudes [3–5]. The negative impact of mass industrialisation is well cited in previous researches [6–10]. Like many other industries, clothing industries are responsible for environmental pollution predominantly through the dyeing, printing, finishing process [11], and garment washing, which increase solid waste in nature [12]. Clothing manufacturing processes release harmful substances, e.g. pesticides, heavy metals and toxic chemicals into the atmosphere [13], which affect biodiversity and human life as well [14]. As a result, textile industries have received increasing attention from environmentalists, suppliers, retailers, designers, consumers and politicians [15]. To reduce the environmental damage by textile products and clothing, the term "eco-fashion" became popular with fashion designers in the recent past [10, 16]. In a general definition "The clothing that causes minimal to zero harm to the environment, produced by organic fibres, in absence of toxic dyes and chemicals, takes into account the human health is called eco-friendly clothing (EFC)" [17–19]. Green, organic, natural, environment and sustainable terms are also used instead of "eco" during promotional practice [20] and in scholarly research [21, 22]. There are many options applied in the textile industry to make clothing environment friendly, e.g. use of sustainably grown fibres like organic cotton, bamboo, hemp or others which require less pesticides and irrigation [23]. Payne [24] and Eryuruk [25] pointed out the "life-cycle thinking in design process" as an alternative route to make clothing eco-friendly. Another approach is the recycling of postconsumer plastic bottles [26] made of polyethylene terephthalate (PET) to weave fabrics [27]. Developing countries are endeavouring to bring consciousness along with sustainable practice to mitigate the environmental impact of textile processing [28, 29]. EFC can reduce the negative impact on the environment by using responsibly sourced products which are either renewable or sustainably harvested [30]. Similarly, Kutsenkova [31] states that sustainable clothing or EFC is produced to reduce textile waste, environmental depletion and unethical treatment of workers. Considering the AASHE (The Association for the Advancement of Sustainability in Higher Education) "sustainability" definition, EFC should be produced by "encompassing human and ecological health, social justice, secure livelihoods and a better world for all generations" [32].

Global environment friendly clothing production and consumption has increased rapidly [33], as has consumers' preference to eco-friendliness [34, 35]. As a result, the demand of green products [36] and EFC has increased significantly [37, 38]. Consumer behaviour in recent era is often influenced by the environmental impact of the clothing which was neglected before [39–41]. Moreover, consumers are becoming aware regarding the clothing they wear and its effects on the environment [42]. Therefore, many pieces of research mainly focus on consumer purchasing intention and perception towards EFC [43–49]. The influencing factors of EFC (eco-labelling strategy, aesthetic value, style, price, comfort, quality and awareness) are well investigated in previous researches [50–56]. Barriers to EFC were also mentioned by Laitala et al. [57], Witek [58] and Young et al. [41]. Surprisingly, fewer researches exist on the exploration of EFC or sustainable fashion awareness and purchasing intension among the textile undergraduates, who are the future professionals in this sector [6, 10]. Additionally, a limited number of research studies on curriculum assessment, exploration of textile and apparel undergraduates' knowledge regarding sustainability and EFC [59, 59]. Landgren and Pasricha [60] concluded the importance of teaching the sustainability concept.

Brosdahl & Carpenter [61] conducted a study on assessing textile and apparel undergraduates' environmental knowledge, concern and responsibility regarding clothing. Kim and Damhorst [62] developed a scale to measure the textile and apparel undergraduates' knowledge about the environmental impact of clothing. Furthermore, Kim and Johnson [63] identified the automation and mass customisation as the most influencing factors for impending apparel production by exploring the perception of apparel undergraduates. To the most excellent of our knowledge, no investigation has been conducted on the EFC perception for Bangladeshi textile undergraduates.

Bangladesh has been receiving an increasing order of EFC from several multinational brands to prevent environmental pollution as it is the second largest exporter of apparel [64, 65]. In the very near future, the nation will require an adequate sum of experts in EFC or sustainable clothing. Kantane et al. [66] stated the changes of demand in career field, asking to change the approach to the main principle of the education system. However, there has been no research addressing how we can prepare the textile undergraduates or pre-professionals for the challenges they will meet in executing sustainable practices in the clothing industry in Bangladesh. The assessment of curriculum compatibility with the employment trend is barely a topic for research in the education system of Bangladesh [67]. The textile education is not an exception and is included in this outline. There is no information on the assessment of the Bangladeshi textile undergraduates' knowledge, curriculum content and overall EFC perception to date. If universities cannot prepare sufficient workforce with contemporary textile knowledge on EFC, clothing industries will face a shortage of necessary human capital to meet the future demand for it. It can create impediments in the position of the second largest exporter since Bangladesh faces the challenge of product diversification [64, 68]. The clothing manufacturers in Bangladesh have taken several initiatives for diversifying apparel products to meet the increasing demand [69] and 40% of them have introduced new products as exportable items [70]. As EFC is a diversified, growing demand product and links to clothing sustainability [60, 71], it is high time to explore the textile undergraduates' knowledge and perception regarding it. Kilbrink and Bjurulf [72] stated that the knowledge learned in institutions is a vital issue of job performance. It also affects the decision making of the career field [73]. It acts as a catalyst for students' attitude to change [74] and can stimulate action [75]. Kallgren and Wood [76] stated that knowledge is used as experiences for future tasks and curriculum is the key to lessen the knowledge gap and modify the education system [77]. Hence, relevant knowledge about EFC is imperative to develop the eco-friendly attitude and make textile undergraduates decisive for future need.

1.1 Research objectives

The aim of this paper was to investigate the textile undergraduates' knowledge and perception towards EFC in relation to curriculum and willingness to contribute towards the EFC issue in the future. The study also emphasises the existing curriculum contents about EFC. This exploratory research will provide textile educators with the understating of undergraduates' knowledge and perception towards EFC. The findings will also provide a lens to understand if further modification is required in the existing curriculum to educate the future workforce properly.

2 Methodology

2.1 Design or approach

An exploratory research approach was followed to evaluate the knowledge and perception towards EFC of the undergraduates' of the Textile Engineering programme. The respondents are enrolled in different universities located in Dhaka city of Bangladesh.

2.2 Population and sampling technique

In standard curriculum, there is no specific course on EFC or sustainability in the Textile Engineering programme of Bangladesh; however, students of the fourth year are taught about clothing sustainability and environmental impact of clothing at two specific courses, i.e. "Environmental Studies" and "Textile & Apparel Merchandising" [78]. The selected topic is embedded in these two courses. The target population of this study are the fourth year students of the undergraduate Textile Engineering programme in Bangladesh. Textile Engineering institutions of Bangladesh provide a BSc degree in Textile Engineering with majors in Yarn Engineering, Fabric Engineering, Wet Process Engineering, Apparel Engineering, Textile

Engineering Management, Textile Fashion Design, Industrial and Production Engineering, Textile Machinery Design and Maintenance, Dyes and Chemical Engineering, and Environmental Science Engineering. The topics included in the aforementioned two courses are environmental impact of textile production, sustainable production process, characterisation and control of textile waste, environmental law, new methods of automatic process control, overview of merchandising, key responsibilities, fashion trends, technological innovation in fibres and fabrics, and analysis of trend and future demand of clothing market. Individual respondents were selected by means of purposive sampling.

2.3 Questionnaire design and data collection

Data collection was performed through a self-administered questionnaire based on the research objectives. The questionnaire was prepared by following the literature on eco-friendly clothing and finalised after the evaluation of two clothing sustainability experts. The questionnaire was designed with a combination of four sections, where the first one was comprised of socio-demographic information of the respondents, the second part contained the fundamental questions about EFC and the curriculum was the third part in the questionnaire. The final section was about the respondents' willingness to contribute to the EFC sector as their dedication can make significant alterations. The option of responses were multiple choice (e.g. "From where did you come to know about EFC?"), yes-no (e.g. "Do you know the manufacturing process of EFC?") and Likert-type scale items (e.g. "To what extent do you agree or disagree with the statement "Satisfactory information included in the existing curriculum on EFC"). In total, there were six demographic questions, six basic questions to measure the knowledge level and eight questions to assess the perception of EFC. Two research assistants were trained up by the principle investigator for data collection with a detailed guideline about the questionnaire. For data collection, faculty members of corresponding institutions were contacted via email or phone for permission to conduct the survey during their lecture. A pilot test was carried out in one of the textile institutions in Dhaka in Bangladesh. The final data consists of 282 respondents with a 94% response rate. Textile undergraduates outside Dhaka are not considered in the study due to the lack of formal approval from corresponding textile institutions.

2.4 Data analysis

Descriptive statistics (frequencies, percentages and central values) were performed by the software SPSS 20 to characterise the collected data. Responses to demographic contents, multiple-choice and Likert-type scale item were used in the results – discussion part of data analysis.

3 Results and discussions

The following subsections provide detailed findings of respondents' demographic characteristics, knowledge level and perception in the context of curriculum and interest to contribute towards EFC.

3.1 Demographic information of respondents

Table 1 shows the demographic information of the respondents. 83.3% of the respondents are male and 16.7% female students. The cultural prospect is explained as a determinant of such a higher portion of male students since traditionally, boys are encouraged towards the scientific domain of study like engineering, which is considered a male-dominated profession [70, 80]. The median age of the respondents is 23.5 years and over half of them are between 23 and 25 years old.

Table 1: Demographic characteristics of respondents

Demographic categories	Frequency (n)	Share (%)
Gender		
Male	235	83.3
Female	47	16.7
Age (in years)		
< 23	126	44.7
23–25	149	52.8
> 25	7	2.5
University grant type		
Public	81	28.7
Private	201	73.1

3.2 Textile undergraduates' knowledge regarding EFC

Firstly, informed respondents were distinguished in the study to investigate their knowledge level. The informed or aware respondents are those of the total respondents who have heard about EFC from different sources before this survey (cf. Table 2).

Afterwards, four basic questions about EFC (production process, raw materials and suitable fibres) were included in the questionnaire to further investigate the informed group of respondents (cf. Tables 3–5).

Table 2: Awareness and source of knowledge of respondents informed about EFC

Source of knowledge about EFC	Awareness about EFC	
	Yes	No
University course	104	50
Family/friends	21	
Seminar/workshop	23	
Newspaper/Magazine	38	
Social Media	40	
Others	6	
Total	232	
Share (%)	82.3	17.7

It is evident that most of the respondents were familiar with the term EFC. 82.3% of the respondents were well-aware about the term. They have learned about EFC from different sources. Among this informed group of respondents, the majority of them have learned about it from their undergraduate course (44.82%), 17.24% from social media, 16.37% from newspapers or magazines, 9.9% from various academic seminars or workshops, 9.05% from friends and relatives, and the rest have learned about EFC from other sources (2.57%). The response to knowledge sources varies and 55.18% of aware respondents have heard the term from other sources apart from university courses. The absence of specific courses on EFC in the existing curriculum is a plausible reason behind this unusually high percentage. Additionally, 17.7% of the respondents were found entirely unaware of it. They became familiar with the term during the survey. 51% of these unaware respondents are from a particular institution where no informed respondents were found. 49% are scattered in another two institutions to which also informed respondents belong. It should be a matter of concern for textile institutions, educators and manufacturers since EFC is the latest trend in the clothing industry [81]. The lack of awareness about it may create an internal threat towards the advancement of the sustainable clothing industry in Bangladesh. Hur and Cassidy [82] stated that the lack of knowledge on sustainability is one of personal and organisational challenges which need to be overcome for a sustainable clothing practice. Kantane et al. [66] stated that awareness is the most significant factor considered by employers. As product knowledge always influences the adaptation of new products [83, 84], professionals are increasingly interested in accumulating knowledge regarding sustainable clothing [21] and hiring knowledgeable workers. Hence, universities need to prepare the undergraduates with relevant knowledge of EFC for future. The findings in Tables 3, 4 and 5 also suggest this statement. Brosdahl and Carpenter [61] concluded that students' learning through a university course about the clothing environmental impact is more effective than the students' learning through mass media.

53.02% of the informed respondents have the knowledge about how EFC is produced. 71.55% of that group ruminate that the production process of EFC is more complicated than conventional clothing (cf. Table 3), while conventional clothing and EFC production are fundamentally similar except for the assembly, use and disposal of environmental concerns [34].

Raw materials are essential for EFC manufacturing as an appropriate selection of raw materials can minimise the overall environmental impact of clothing during its life cycle [34]. The respondents were further asked to choose the features of the raw

Table 3: Knowledge about production process of EFC

Knowledge about manufacturing process of EFC	Process complication of EFC compared to conventional clothing		Frequency (n)	Share (%)
	Yes	No		
Yes	95	28	123	53.02
No	71	38	109	46.98
Frequency (n)	166	66	232	
Share (%)	71.55	28.45		100

Table 4: Knowledge about features of EFC raw materials

Response of students	Frequency (n)	Share (%)
Organic	98	42.2
Sustainable	26	11.2
Recycled	25	10.8
All of the above	83	35.8

material of EFC. 42.2% of the respondents know that EFC is produced only from organic material, 11.2% think about sustainable material and 10.8% about recycled material. 35.8% of the informed respondents have adequate knowledge about the raw materials of EFC as they correctly respond to all of the features that can make clothing eco-friendly (cf. Table 4). The valuable characteristics of eco-friendly materials are renewable, biodegradable, non-toxic, recyclable and reusable [34, 85]. Moreover, EFC materials include ethics, energy consumption and sustainability of resource consumption [86]. Chen and Lewis [87] stated that the material choice of EFC incorporates the environmental impact from production to disposal of the finished clothing.

Table 5: Response to suitable fibres for EFC

Response of students	Frequency (n)	Share (%)
Conventional Cotton	122	52.59
Organic cotton	86	37.07
Bamboo	5	2.16
Hemp	6	2.58
Flax	0	0
Recycled polyester	13	5.60

On identifying or responding to suitable fibres, 52.59% of the aware respondents believe that conventional cotton is the only suitable fibre for EFC, whereas it consumes a massive amount of water [88] and harmful toxic chemicals during its production [89–91]. Globally, conventional cotton consumes 22.5% of all insecticides [92] and 2.6% of the full water footprint [93]. On the other hand, 37.07% believe that organic cotton is suitable for EFC (cf. Table 5). Organic cotton is produced without any harmful chemical fertilisers and pesticides [94]. Basically, growing organic cotton is a systematic approach of organic forming [95] and the best choice to avoid environmental damage [92]. 2.16% and 2.58% of the respondents selected bamboo and hemp, respectively, as suitable fibres for EFC (cf. Table 5). The percentage is comparatively lower than for other fibres. It is evident that the majority of aware undergraduates are not well informed about bamboo or hemp as a sustainable or environment friendly fibre. Bamboo fibres have vast application areas for being a sustainable material [96]. It is one of suitable fibres for EFC [81] as it is biodegradable, renewable and can be grown without pesticides or other chemicals [64, 97]. Furthermore, merely 4.9% know about recycled polyester, which is another indication of their inadequate knowledge since recycled polyester has emerging applications in the clothing factory [98].

3.3 Curriculum perception

Curriculum planning is imperative to teach a particular course at a college or university level programme [99] as knowledge level and performance are relevant to the programme curriculum [100]. Although courses on EFC are absent in the existing curriculum, overall curriculum perception regarding EFC is considered in this study. The outcomes of the curriculum perception investigation are summarised in Tables 6 and 7.

Table 6: Undergraduates' response regarding existing curriculum on EFC

Response of students	Satisfactory information included in existing curriculum on EFC		Received information from academic seminar/workshop on EFC	
	Frequency (n)	Share (%)	Frequency (n)	Share (%)
Strongly disagree	36	12.8	48	17.0
Disagree	43	15.2	52	18.4
Neutral	80	28.4	59	20.9
Agree	98	34.8	97	34.4
Strongly agree	25	8.9	26	9.2

Table 7: Undergraduates' expectation regarding curriculum

Response of students	Willing to learn more about EFC through curriculum		Need one special course on EFC in curriculum	
	Frequency (n)	Share (%)	Frequency (n)	Share (%)
Strongly disagree	5	1.8	7	2.5
Disagree	9	3.2	4	1.4
Neutral	42	14.9	19	6.7
Agree	79	28.0	87	30.9
Strongly agree	147	52.1	165	58.5

Concerning the curriculum, 43.7% of the respondents are satisfied (either agreed or strongly agreed) with the information on EFC that they receive from their institutions through the existing curriculum. Similarly, 43.6% either agreed or strongly agreed on obtaining the necessary information through a seminar or workshop. On the other hand, 28% of the respondents disagreed and 28.4% remained neutral about the existing curriculum. 56.3% of the respondents answered unfavourably about the academic seminar or workshop on EFC (cf. Table 6).

The respondents' expectation regarding the curriculum was also examined in the study. Both, the informed and unaware respondents, were found interested in learning about EFC from their course contents. 80.1% of all respondents either agreed or strongly agreed to learn more about EFC. Furthermore, 89.4% of the respondents expect a minimum of one particular course on the details of EFC from their existing curriculum (cf. Table 7). The findings of the respondents' knowledge and curriculum perception raise the questions of the existing curriculum modification regarding clothing sustainability or EFC. The respondents' inconsistent responses on the fundamental questions regarding EFC and curriculum perception provide a clear indication about the requirement for specific courses on EFC in the existing curriculum. Palma et al. and Cezarino et al. also emphasised the inclusion of sustainability in the subjects of the educational curriculum in their studies [101, 102]. A well-defined and organised curriculum, consisting of the theoretical and practical framework, can help educators prepare undergraduates with current knowledge and improve outcomes [103,104]. Ellis [105] stated that an academic curriculum is a knowledge-centred curriculum where students are expected to acquire knowledge as a foundation of their future life. Coate and Barnett [106] stated that curriculum is the key concept of university study and it is the cornerstone of knowledge, learning and understanding. They mentioned that ideas of higher education are put into action in society through the curriculum. Hence, a contemporary curriculum on EFC contents will facilitate awareness among textile undergraduates, which will help them in their future careers.

3.4 Willingness to contribute towards EFC

The manufacturers and retailers of the clothing industry are attempting to meet the demand for EFC [107,108] due to the emerging demand for it [109]. As textile undergraduates are future professionals of the clothing industry, it is necessary to explore how they perceive EFC and how they want to contribute to this sector. Firstly, they were asked about the prospect of EFC in the clothing industry. 65.6% of the total respondents believe that EFC will be the future face of the clothing business (cf. Table 8). The findings support the results obtained in Tables 6 and 7. Csanák [16] and Mora et al. [21] stated that eco-fashion is a part of the sustainability trend and will be a great topic of all fashion forums.

Table 8: Students' opinion about future of EFC in clothing industry

Response of students	Frequency (n)	Share (%)
Yes	185	65.6
No	7	2.5
Not sure	90	31.9

In contrast, 31.9% of the respondents are not sure about the prospect of EFC. This high percentage is unusual as respondents are textile undergraduates. The responsibility goes to textile institutions and educators to make them aware of EFC as universities are the centres of knowledge sharing

[110]. Similarly, Kong et al. [75] identified public education as a knowledge source of sustainable fashion products. Therefore, it is necessary to provide a more contemporary curriculum supported by accurate information on EFC.

Table 9: Undergraduates' willingness to contribute towards EFC

Response	Frequency (n)	Share (%)
Yes	265	94.0
No	17	6.0

94.0% of the respondents showed interest to contribute to the future development of EFC in Bangladesh (cf. Table 9). This was further investigated, namely how these optimistic students may keep a role in the future development of EFC (cf. Table 10). Among them, 52.4% want to contribute through research which is admirable since Gam [111] stated that the understanding of the EFC sector needs more research in purchasing behaviour and others. Along with the inclusion of EFC and sustainability course, an extensive research facility within the university is also necessary to achieve a satisfactory knowledge level of the students [102]. 11.3% of the respondents want to become entrepreneurs and 14.2% want to innovate new business ideas to promote EFC. Ozdamar Ertekin and Atik [112] described that an innovative business model for ecological clothing can make a tremendous effect to move people away from the phenomenon of fast fashion.

Table 10: Ways of contribution to EFC by undergraduates

Response of students	Frequency (n)	Share (%)
Research	145	52.4
Developing awareness	48	17.0
Innovating business ideas	40	14.2
Entrepreneur	32	11.3

17% of the EFC enthusiastic students have a goal to create awareness by sharing information among consumers in the future through the help of mass media (cf. Table 10). Buzzo and Abreu [113] stated that social networks can drastically make alterations in the fashion world. Moreover, it can enable the perception of the product's value to the user [114].

4 Conclusion

Internationally, EFC is one of the leading concepts in the clothing industry and sustainable fashion. Its growing global acceptance may reduce the environmental damage considerably. In this study, Bangladeshi textile undergraduates' knowledge of EFC from their existing curriculum was evaluated. After analysing the undergraduates' knowledge and perception towards EFC, three notable findings were revealed in the study. The first one is the knowledge gap about EFC among Bangladeshi textile undergraduates. Secondly, it can be said that the students' perception of EFC, along with their interest in learning and contribution, is very optimistic for the Bangladeshi clothing industry. Thirdly, a critical evaluation and modification are needed of the existing curriculum of the Textile Engineering programme to synchronise with more profound concepts of EFC. Therefore, the most plausible solution to mitigate this state of reverse direction is to incorporate EFC and sustainability courses in the existing curriculum of the Textile Engineering programme. In this way, textile universities and educators can prepare future professionals for the impending sustainable clothing industry. This study is one of the first assessments of knowledge and perception towards EFC for Bangladeshi textile undergraduates. However, it had some limitations. The main limitation of the study was the small sample size. A census on all textile undergraduates may provide more in-depth information, considering time and cost. Secondly, the study did not evaluate the curriculum of EFC related courses of the universities. A curriculum evaluation may provide further information about the inconsistencies observed in the findings. Further research on the investigation of the knowledge and perception towards circular fashion and clothing sustainability, along with an assessment of the existing curriculum regarding these topics, would give more comprehensive results about the sustainability education of Bangladeshi textile undergraduates.

Acknowledgements

The authors are very grateful to Md. Solaiman Hossain and Maruf Niaz for the support of data collection.

Funding: No funding has been received for this research.

Conflict of interest: No conflict of interest has been declared.

References

1. BLY, S., GWOZDZ, W., REISCH, L.A. Exit from the high street: An exploratory study of sustainable fashion consumption pioneers. *International Journal of Consumer Studies,* 2015, **39**(2), 125–35, doi: 10.1111/ijcs.12159.
2. ROY CHOUDHURY, A.K. Environmental impacts of the textile industry and its assessment through life cycle assessment. In *Roadmap to sustainable textiles and clothing: environmental and social aspects of textiles and clothing supply chain*. Edited by Subramanian Senthilkannan Muthu. Singapore : Springer, 2014, 1–33, doi: 10.1007/978-981-287-110-7_1.
3. BOONE, T. Sustainable Fashion and Textiles: Design Journeys by Kate Fletcher (Earthscan, 2008). Fashion Practice, 2009, **1**(2), 271–4, doi: 10.2752/175693809X469229
4. MAHAJAN, S. Sustainability of green fashion. In *RMUTP International Conference: Textiles & Fashion*, Bangkok, Thailand, 2012, 97(12A), 1–11.
5. RAZZAQ, A., ANSARI, N.Y., RAZZAQ, Z., AWAN, H.M. The impact of fashion involvement and pro-environmental attitude on sustainable clothing consumption: the moderating role of Islamic religiosity. *SAGE Open*, 2018, **8**(2), 1–17, doi: 10.1177/2158244018774611.
6. ADJAINO, O.V., ISIBOR, O.F., OGEH, E.B. Green purchase intention amongst undergraduates: evidence from the University of Benin. *Management Sciences Review*, 2019, **10**(1), 134–148.
7. FORSMAN, L., MADSEN, D. *Consumers' attitudes towards sustainability and sustainable labels in the fashion industry : a qualitative study : student thesis*. The Swedish School of Textiles, University of Boras, 2017, http://www.diva-portal.se/smash/get/diva2:1143596/FULLTEXT01.pdf.
8. PRABUSANKAR, R. A Study on consumer's perception and purchase intentions towards eco-friendly products. *Asian Journal of Research in Social Sciences and Humanities*, 2016, **6**(8), 1794–1802, doi: 10.5958/2249-7315.2016.00711.5.
9. RAMLOGAN, R. Environment and human health: a threat to all. *Environmental Management and Health*, 1997, **8**(2), 51–66, doi: 10.1108/09566169710166548.
10. THOMPSON, A., TONG, X. Factors influencing college students purchase intention towards Bamboo textile and apparel products. *International Journal of Fashion Design, Technology and Education*, 2016, **9**(1), 62–70, doi: 10.1080/17543266.2015.1132781.
11. DE BRITO, M.P., CARBONE, V., BLANQUART, C.M. Towards a sustainable fashion retail supply chain in Europe: organisation and performance. *International Journal of Production Economics*, 2008, **114**(2), 534–153, doi: 10.1016/j.ijpe.2007.06.012.
12. RESTA, B., GAIARDELLI, P., PINTO, R., DOTTI, S. Enhancing environmental management in the textile sector: An organisational-life cycle assessment approach. *Journal of Cleaner Production*, 2016, **135**, 620–632, doi: 10.1016/j.jclepro.2016.06.135.
13. ROOS, S., POSNER, S., JÖNSSON, C., PETERS, G.M. Is unbleached cotton better than bleached? Exploring the limits of life-cycle assessment in the textile sector. *Clothing and Textiles Research Journal*, 2015, **33**(4), 231–147, doi: 10.1177/0887302X15576404.
14. CONNELL, K.Y.H., KOZAR, J.M. Environmentally sustainable clothing consumption: knowledge, attitudes, and behavior. In *Roadmap to sustainable textiles and clothing: environmental and social aspects of textiles and clothing supply chain*. Edited by Subramanian Senthilkannan Muthu. Singapore : Springer, 2014, doi: 10.1007/978-981-287-110-7_2.
15. AUSTGULEN, M.H. Environmentally sustainable textile consumption – what characterizes the political textile consumers? *Journal of Consumer Policy*, 2016, **39**, 441–466, doi: 10.1007/s10603-015-9305-5.
16. CSANÁK, E. Eco-friendly concepts and ethical movements in the fashion industry. *In 7th International textile, clothing & design conference: magic world of textiles, Dubrovnik*, 2014. Edited by Zvonko Dragčević. Zagreb : University of Zagreb, 2014, 1–7.
17. CHEN, T.B., CHAI, L.T. Attitude towards the environment and green products: consumers' perspective. Management Science and Engineering, 2010, 4(2), 27–39, doi. 10.3968/j.mse.1913035X20100402.002.
18. JOERGENS, C. Ethical fashion: myth or future trend? *Journal of Fashion Marketing and Management,* 2006, **10**(3), 360–371, doi: 10.1108/13612020610679321.
19. NIINIMÄKI, K. Eco-clothing, consumer identity and ideology. Sustainable Development, 2010, **18**(3), 150–162, doi: 10.1002/sd.455.

20. PEIRSON-SMITH, A., EVANS, S. Fashioning green words and eco language: an examination of the user perception gap for fashion brands promoting sustainable practices. *Fashion Practice*, 2017, **9**(3), 373–397, doi: 10.1080/17569370.2017.1366688.
21. MORA, E., ROCAMORA, A., VOLONTÉ, P. On the issue of sustainability in fashion studies. *International Journal of Fashion Studies*, 2014, **1**(2), 139–147, doi: 10.1386/infs.1.2.139_1.
22. PREETI, S., SINGH, N. Impact of eco-friendly products on consumer behavior. *CBS E-Journal, Biz n Bytes,* 2010, **6**, 1–16, http://cbsmohali.org/img/chapter6.pdf.
23. CLAUDIO, L. Waste couture: environmental impact of the clothing industry. *Environmental Health Perspective*, 2007, **115**(9), 449–454, doi: 10.1289/ehp.115-a449.
24. PAYNE, A. The life-cycle of the fashion garment and the role of Australian mass market designers. *International Journal of Environmental, Cultural, Economic and Social Sustainability*, 2011, **7**(3), pp. 237–246.
25. ERYURUK, S.H. Greening of the textile and clothing industry. *Fibres & Textiles in Eastern Europe*, 2012, **20**(6A(95)), 22–27.
26. HOSSAIN, M., SHAMS, A. Export potential of recycled plastic: a study on Bangladesh. *Asian Social Science*, 2020, **16**(3), 1–17.
27. RADHAKRISHNAN, S. Fashion Industry and Sustainability. In *Handbook of sustainable apparel production*. Edited By Subramanian Senthilkannan Muthu. CRC Press, Taylor and Francis Group, 2015, 522–523.
28. VADICHERLA, T., SARAVANAN, D. Eco design/sustainable design of textile products. In *Handbook of sustainable apparel production*. Edited By Subramanian Senthilkannan Muthu. CRC Press, Taylor and Francis Group, 2015, 491–492.
29. HONG, H., KANG, J. The impact of moral philosophy and moral intensity on purchase behavior toward sustainable textile and apparel products. *Fashion and Textiles*, 2019, **6**(1), 1–22, doi: 10.1186/s40691-019-0170-8.
30. ROWLANDS, I. Consumer perceptions of "green power". *Journal of Consumer Marketing*, 2002, **11**(4), 112–129, doi: 10.1108/07363760210420540.
31. KUTSENKOVA, Z. Dominican scholar the sustainable future of the modern fashion industry: Honors Thesis. Dominican University of Califormia, 2017, doi: 10.33015/dominican.edu/2017.HONORS.ST.02.
32. O'CONNOR, T., GRAY, J. Incorporating sustainability across the curriculum. *Sustainability: The Journal of Record*, 2016, **9**(1), 21–24, doi: 10.1089/SUS.2016.29037.
33. SHAW, D., HOGG, G., WILSON, E., SHIU, E., HASSAN, L. Fashion victim: the impact of fair trade concerns on clothing choice. *Journal of Strategic Marketing*, 2006, **14**(4), 427–440, doi: 10.1080/09652540600956426.
34. KHAN, M.M.R., ISLAM, M.M. Materials and manufacturing environmental sustainability evaluation of apparel product: knitted T-shirt case study. *Textiles and Clothing Sustainability*, 2015, **1**(8), 1-12, doi: 10.1186/s40689-015-0008-8.
35. ZIMMER, M.R., STAFFORD, T.F., STAFFORD, M.R. Green issues: dimensions of environmental concern. *Journal of Business Research*, 1994, **3**(1), 63–74, doi: 10.1016/0148-2963(94)90069-8.
36. MAKOWER, J., PIKE, C. *Strategies for the green economy: opportunities and challenges in the new world of business*. New York : McGraw- Hill, 2008, 40–50.
37. FISHER, C., BASHYAL, S., BACHMAN, B. Demographic impacts on environmentally friendly purchase behaviors. *Journal of Targeting, Measurement and Analysis for Marketing*, 2012, **20**(3), 172–184, doi: 10.1057/jt.2012.13.
38. MAINIERI, T., BARNETT, E.G., VALDERO, T.R., UNIPAN, J.B., OSKAMP, S. Green buying: the influence of environmental concern on consumer behavior. *The Journal of Social Psychology*, 1997, **137**(2), 189–204, doi: 10.1080/00224549709595430.
39. HAUG, A., BUSCH, J. Towards an ethical fashion framework. *Fashion Theory*, 2016, **20**(3), 317–339, doi: 10.1080/1362704X.2015.1082295.
40. TUNG, T., KOENIG, H.F., CHEN, H.L. Effects of green self-identity and cognitive and affective involvement on patronage intention in eco-friendly apparel consumption: A gender comparison. *Sustainability*, 2017, **9**(11), 1–17, doi: 10.3390/su9111977.
41. YOUNG, W., HWANG, K., McDONALD, S., OATES, C.J. Sustainable consumption: green consumer behaviour when purchasing products. *Sustainable Development*, 2009, **18**, 20–31, doi: 10.1002/sd.394.
42. CONNELL, K.Y.H. Exploring consumers' perceptions of eco-conscious apparel acquisition be-

haviors. *Social Responsibility Journal*, 2011, **7**(1), 61–73, doi: 10.1108/17471111111114549.

43. HUSTVEDT, G., BERNARD, J.C. Consumer willingness to pay for sustainable apparel: the influence of labelling for fibre origin and production methods. *International Journal of Consumer Studies*, 2008, **32**(5), 491–498, doi: 10.1111/j.1470-6431.2008.00706.x.
44. SARICAM, C., OKUR, N. Analysing the consumer behavior regarding sustainable fashion using theory of planned behavior. In *Consumer behaviour and sustainable fashion consumption. Textile science and clothing technology*. Edited by Subramanian Senthilkannan Muthu. Singapore : Springer, 2019, 1–37, doi: https://doi.org/10.1007/978-981-13-1265-6_1.
45. LEE, S. Consumers' Purchasing Intentions toward Sustainable Apparel in US. *Journal of Fashion Business*, 2010, **14**(3), 146–153.
46. NAM, C., DONG, H., LEE, Y.A. Factors influencing consumers' purchase intention of green sportswear. *Fashion and Textiles*, 2017, **4**(2), 1–17, doi: 10.1186/s40691-017-0091-3.
47. RU, K. Consumer perceptions on sustainable fashion and strategy for competitiveness. *Journal of Fashion Technology & Textile Engineering*, 2018, **6**(2), 1–4, doi: 10.4172/2329-9568.1000172.
48. WAGNER, M., CURTEZA, A., CHEN, Y., THOMASSEY, S., ZENG, X. Environmentally-friendly perception of fashion products: a Kansei study. In *Proceedings of the 7th International Conference on Kansei Engineering and Emotion Research 2018. KEER 2018. Advances in Intelligent Systems and Computing, vol. 739*. Edited by Lokman A., Yamanaka T., Lévy P., Chen K., Koyama S. Singapore : Springer, doi: 10.1007/978-981-10-8612-0_39.
49. KOSZEWSKA, M. Social and eco-labelling of textile and clothing goods as a means of communication and product differentiation. Fibres & Textiles in Eastern Europe, 2011, 9(4(87)), 20–26, http://www.fibtex.lodz.pl/article536.html.
50. HUSTVEDT, G., DICKSON, M.A. Consumer likelihood of purchasing organic cotton apparel: influence of attitudes and self-identity. *Journal of Fashion Marketing and Management*, 2009, **13**(1), 49–65, https://doi.org/10.1108/13612020910939879.
51. LUNDBLAD, L., DAVIES, I.A. The values and motivations behind sustainable fashion consumption. *Journal of Consumer Behaviour*, 2016, **15**(2), 149–162, doi: 10.1002/cb.1559.
52. CONNELL, K.Y.H. Internal and external barriers to eco-conscious apparel acquisition. *International Journal of Consumer Studies*, 2010, **34**(3), 279–286, doi: 10.1111/j.1470-6431.2010.00865.x.
53. BROSDAHL, D.J.C., CARPENTER, J.M. Consumer knowledge of the environmental impacts of textile and apparel production, concern for the environment, and environmentally friendly consumption behavior. *Journal of Textile and Apparel, Technology and Management*, 2010, **6**(4), 1–9.
54. OKUR, N., SARICAM, C. The impact of knowledge on consumer behaviour towards sustainable apparel consumption. In *Consumer behaviour and sustainable fashion consumption. textile science and clothing technology*. Edited by Subramanian Senthilkannan Muthu. Singapore : Springer, 2019, doi: 10.1007/978-981-13-1265-6_3.
55. SOBUJ, M., KHAN, A.M., HABIB, M.A., ISLAM, M.M. Factors influencing eco-friendly apparel purchase behavior of Bangladeshi young consumers: case study. *Research Journal of Textile and Apparel*, 2021, **25**(2), 139–157, doi: 10.1108/RJTA-10-2019-0052.
56. LAITALA, K., AUSTGULEN, M.H., KLEPP, I.G. Responsibility without means. In *Roadmap to sustainable textiles and clothing: environmental and social aspects of textiles and clothing supply chain*. Edited by Subramanian Senthilkannan Muthu. Singapore : Springer, 2014, 125–151, doi: 10.1007/978-981-287-065-0.
57. WITEK, L. Attitude-behaviour gap among polish consumers regarding green purchases. *Visegrad Journal on Bioeconomy and Sustainable Development*, 2019, **8**(1), 31–36, doi: 10.2478/vjbsd-2019-0006.
58. CONNELL, K.Y.H., KOZAR, J.M. Sustainability knowledge and behaviors of apparel and textile undergraduates. *International Journal of Sustainability in Higher Education*, 2012, **13**(4), 394-407, doi: 10.1108/14676371211262335
59. LAUGHLIN, J., KEAN, R.C. Assessment of textiles and clothing academic programs in the United States. *Clothing and Textiles Research Journal*, 1995, **13**(3), 184–199, doi: 10.1177/0887302X9501300305.
60. LANDGREN, T.M., PASRICHA, A. Transforming the fashion and apparel curriculum to incorporate sustainability. *International Journal of Fashion Design, Technology and Education*, 2011, **4**(3), 187-196, doi: 10.1080/17543266.2011.613856.

61. BROSDAHL, D.J.C., CARPENTER, J.M. Is green the new black? Assessing textile & apparel undergraduate students' environmental knowledge, concern and responsibility. *Journal of Textile and Apparel, Technology and Management*, 2011, **7**(2), 1–15.
62. KIM, H.S., DAMHORST, M.L. Environmental concern and apparel consumption. *Clothing and Textiles Research Journal*, 1998, **16**(3), 126–133, doi: 10.1177/0887302X9801600303.
63. KIM, E., JOHNSON, K.K.P. The U.S. apparel industry: futuring with undergraduate students in apparel majors. *Clothing and Textiles Research Journal,* 2007, **25**(4), 283–306, doi: 10.1177/0887302X07306909.
64. HOSSIAN, M.S., KABIR, R., LATIFEE, E.H. Export competitiveness of Bangladesh Readymade Garments sector. *International Journal of Research in Business and Social Science*, 2019, **8**(3), 45–63, 10.20525/ijrbs.v8i3.205.
65. KHAN, A.N., ULLAH, M.R. Export scenario between Bangladesh and China: opportunities of Bangladesh in RMG sector. European Scientific Journal, 2017, **13**(28), 299–320.
66. KANTANE, I., SLOKA, B., BULIGINA, I., TORA, G., BUSEVICA, R., BULIGINA, A., DZELME, J., TORA, P. Expectations by employers on skills, knowledge and attitudes of employees. *European Integration Studies*, 2015, 9(1), 224-234.
67. RASHID, M.M.U., RHMAN, M.Z. Quality of higher education in Bangladesh: application of a modified SERVQUAL model. *Problems of Education in the 21st Century,* 2017, **75**(1), 72–91.
68. RAKIB, M.A., ADNAN, A. Challenges of Ready-Made Garments sector in Bangladesh: ways to overcome. *BUFT J*ournal, 2015, 3, 77–90.
69. AHMED, R., ISLAM, T., AL-AMIN, M. The effects of market diversification activities on Bangladesh RMG export. *International Journal of Economics and Financial Issues*, 2013, **3**(4), 938–948.
70. ALAM, M.S., SELVANATHAN, E.A., SELVANATHAN, S. Determinants of the Bangladesh garment exports in the post-MFA environment. *Journal of the Asia Pacific Economy*, 2017, **22**(2), 330–352, doi: 10.1080/13547860.2017.1292768.
71. CERVELLON, M., HJERTH, H., RICARD, S., CAREY, L. Green in fashion? An exploratory study of national differences in consumers concern for eco-fashion. In *Proceedings of 9th International Marketing Trends Conference, Venice, January 20-21,* 2010, http://researchonline.gcu.ac.uk/cbs/148.
72. KILBRINK, N., BJURULF, V. Transfer of knowledge in technical vocational education: a narrative study in Swedish upper secondary school. *International Journal of Technology and Design Education*, 2013, **23**, 519–535, doi: 10.1007/s10798-012-9201-0.
73. BRUCKS, M. The effects of product class knowledge on information search behavior. *Journal of Consumer Research*, 1985, **12**(6), 1–16, doi: 10.1086/209031.
74. ARBUTHNOTT, K.D. Education for sustainable development beyond attitude change. *International Journal of Sustainability in Higher Education*, 2009, **10**(2), 152-163, doi: 10.1108/14676370910945954.
75. KONG, H.M., KO, E., CHAE, H., MATTILA, P. Understanding fashion consumers' attitude and behavioral intention toward sustainable fashion products: focus on sustainable knowledge sources and knowledge types. *Journal of Global Fashion Marketing*, 2016, **7**(2), 103–119, doi: 10.1080/20932685.2015.1131435.
76. KALLGREN, C.A., WOOD, W. Access to attitude-relevant information in memory as a determinant of attitude-behavior consistency. *Journal of Experimental Social Psychology*, 1986, **22**(4), 328–338, doi: 10.1016/0022-1031(86)90018-1.
77. ANNALA, J., LINDEN, J., MÄKINEN, M. Curriculum in Higher Education Research. In *Researching higher education: international perspectives on theory, policy and practice*. Edited by Jennifer M. Case, Jeroen Huisman. London : Routledge, 2016, 171–189.
78. Bangladesh University of Textiles (BUTEX) (2016*). Academic regulation, course structure and detailed syllabus for the B.Sc. in textile engineering courses*. Registrar Office, Bangladesh University of Textiles, 29–77.
79. RICHMAN, L.S., VANDELLEN, M., WOOD, W. How women cope: being a numerical minority in a male-dominated profession. *Journal of Social Issues*, 2011, **67**(3), 492–509.
80. SAIFUDDIN, S.M., DYKE, L., RASOULI, M. Factors affecting the choice of high tech engineering majors for university women and men in Bangladesh. In *AMCIS 2011 Proceedings*, https://aisel.aisnet.org/amcis2011_submissions/403.
81. KHANDUAL, A., PRADHAN, S. Fashion brands and consumers approach towards sustainable

fashion. In *Fast fashion, fashion brands and sustainable consumption. Textile science and clothing technology*. Edited by Subramanian Senthilkannan. Singapore : Springer, 2019, 37–54, doi:10.1007/978-981-13-1268-7_3.

82. HUR, E., CASSIDY, T. Perceptions and attitudes towards sustainable fashion design: challenges and opportunities for implementing sustainability in fashion. *International Journal of Fashion Design, Technology and Education*, 2019, **12**(2), 208–217, doi: 10.1080/17543266.2019.1572789.
83. KOLYESNIKOVA, N., LAVERIE, D.A., DUHAN, D.F., WILCOX, J.B., DODD, T.H. The influence of product knowledge on purchase venue choice: does knowing more lead from bricks to clicks? *Supply Chain Forum: An International Journal*, 2010, **11**(1), 28–40, doi: 10.1080/16258312.2010.11517223.
84. SUJAN, M. Consumer knowledge: effects on evaluation strategies mediating consumer judgments. *Journal of Consumer Research*, 1985, **12**(1), 31–46, doi: 10.1086/209033.
85. ROY CHOUDHURY, A.K. Green chemistry and the textile industry. *Textile Progress*, 2013, **45**(1), 3–143, doi: 10.1080/00405167.2013.807601.
86. MUTHU, S.S., LI, Y., HU, J., MOK, T.P.Y. An exploratory comparative study on eco-impact of paper and plastic bags firefighter protective clothing view project an exploratory comparative study on eco-impact of paper and plastic bags. *Journal of Fiber Bioengineering and Informatics*, 2009, **1**(4), 307–320.
87. CHEN, C., LEWIS, V.D. The life of a piece of cloth: developing garments into a sustainable service system. *The International Journal of Environmental, Cultural, Economic, and Social Sustainability: Annual Review*, 2006, **2**(1), 197–207, doi: 10.18848/1832-2077/CGP/v02i01/54324.
88. SANDIN, G., PETERS, G.M. Environmental impact of textile reuse and recycling – a review. *Journal of Cleaner Production*, 2018, **184**, 353–365, doi: 10.1016/j.jclepro.2018.02.266.
89. ALLWOOD, J., LAURSEN, S., DE RODRIGUEZ, C., BOCKEN, N. Well dressed? The present and future sustainability of clothing and textiles in the United Kingdom. *Journal of the Home Economics Institute of Australia*, 2015, **22**(1), 42.
90. De COSTER, J. Green textiles and apparel: environmental impact and strategies for improvement. *Text Outlook International*, 2007, **132**, 143–164.
91. RUSINKO, C.A. Green manufacturing: an evaluation of environmentally sustainable manufacturing practices and their impact on competitive outcomes. *IEEE Transactions on Engineering Management*, 2007, **54**(3), 445–454, doi: 10.1109/TEM.2007.900806.
92. VENKATESAN, H., PERIYASAMY, A.P. Ecofibers in the textile industry. In *Handbook of ecomaterials*. Edited by Martínez L., Kharissova O., Kharisov B. Cham : Springer, 2019, 1417-1420, doi: 10.1007/978-3-319-68255-6_25.
93. HOEKSTRA, A.Y., CHAPAGAIN, A.K. *Globalization of water: sharing the planet's freshwater resources*. Oxford : Blackwell Publishing, 2008, 103–123.
94. RAMASAMY, K.M. Comparative study of organic and regular cotton knitted fabrics. *Research Journal of Textile and Apparel*, 2015, **19**(3), 45–51, doi: 10.1108/RJTA-19-03-2015-B006.
95. EYHORN, F., RAMAKRISHNAN, M., MÄDER, P. The viability of cotton-based organic farming systems in India. International Journal of Agricultural Sustainability, 2007, **5**(1), 25–38, doi: 10.1080/14735903.2007.9684811.
96. BYSTRIAKOVA, N., KAPOS, V., LYSENKO, I., STAPLETON, C.M.A. Distribution and conservation status of forest bamboo biodiversity in the Asia-Pacific Region. *Biodiversity & Conservation*, 2003, **12**(9), 1833–1841, doi: 10.1023/A:1024139813651.
97. WAITE, M. Sustainable textiles: The role of bamboo and a comparison of bamboo textile properties (part II). *Journal of Textile and Apparel, Technology and Management*, 2010, **6**(3), 1–21.
98. RADHAKRISHNAN, S., VETRIVEL, P., VINODKUMAR, A., PALANISAMI, H. Recycled polyester - tool of savings in the use of virgin raw material. In *Environmental footprints of recycled polyester. textile science and clothing technology*. Edited by Subramanian Senthilkannan Muthu. Singapore : Springer, 2020, 49–83, doi: 10.1007/978-981-13-9578-9_3.
99. STARK, J.S., LOWTHER, M.A., SHARP, S., ARNOLD, G.L. Program-level curriculum planning: an exploration of faculty perspectives on two different campuses. *Research in Higher Education*, 1997, **38**(1), 99–130, doi: 10.1023/A:1024952829701.
100. LUCKETT, K. The relationship between knowledge structure and curriculum: a case study in

sociology. *Studies in Higher Education,* 2009, **34**(4), 441–453, doi: 10.1080/03075070902772018.

101. ALISMAIL, H.A., McGUIRE, P. 21st century standards and curriculum: current research and practice. *Journal of Education and Practice*, 2015, **6**(6), 150–154, http://files.eric.ed.gov/fulltext/EJ1083656.pdf.
102. LOMBARDI, M.M., OBLINGER, D.G. (Ed.) *Authentic learning for the 21st century: an overview*. EDUCAUSE Learning Initiative, 2007, http://alicechristie.org/classes/530/EduCause.pdf.
103. ELLIS, A.K. *Exemplars of curriculum theory*. New York : Taylor & Francis, 2014, 163 p.
104. COATE, K., BARNETT, R. *Engaging the curriculum in higher education*. New York : The Society for Research into Higher education & Open University Press, 2005, 25 p.
105. SHIM, S., KIM, J., NA, Y. An exploratory study on up-cycling as the sustainable clothing life at home. *Fashion and Textiles*, 2018, **5**(1), 1–15, doi: 10.1186/s40691-018-0129-1.
106. WILLIAMS, M. Going young, green and local. *WWD Women's Wear Dly*. 2008, **196**(7), 10.
107. HAN, H., HSU, L.T.J., SHEU, C. Application of the theory of planned behavior to green hotel choice: testing the effect of environmental friendly activities. *Tourism Management*, 2010, **31**(3), 325–334, doi: 10.1016/j.tourman.2009.03.013.
108. TAM, M. Measuring the effect of higher education on university students. *Quality Assurance in Education,* 2002, **10**(4), 223–228, doi: 10.1108/09684880210446893.
109. GAM, H.J. Are fashion-conscious consumers more likely to adopt eco-friendly clothing? *Journal of Fashion Marketing and Management*, 2011, **15**(2), 178–193, doi: 10.1108/13612021111132627.
110. OZDAMAR ERTEKIN, Z., ATIK, D. Sustainable markets: motivating factors, barriers, and remedies for mobilization of slow fashion. *Journal of Macromarketing,* 2015, **35**(1), 53–69, doi: 10.1177/0276146714535932.
111. BUZZO, A., ABREU, M.J. Fast fashion, fashion brands and sustainable consumption. In *Fast fashion, fashion brands and sustainable consumption*. Edited by Subramanian Senthilkannan Muthu. Singapore : Springer Singapore, 2019, 1–17, doi: 10.1007/978-981-13-1268-7_1.
112. WOLNY, J., MUELLER, C. Analysis of fashion consumers' motives to engage in electronic word-of-mouth communication through social media platforms. *Journal of Marketing Management,* 2013, **29**(5–6), 562–583, doi: 10.1080/0267257X.2013.778324.

Mebrahtom Teklehaimanot[1], Kiday Fisseha[2], Million Ayele[3]
[1] Mekelle University, Ethiopian Institute of Technology,
Department of Garment and Textile Engineering, Mekelle, Ethiopia
[2] Aksum University, Aksum Institute of Technology, Faculty of Textiles and Fashion Technology, Aksum, Ethiopia
[3] Bahir Dar University, Ethiopian Institute of Textile and Fashion Technology, 1037, Bahir Dar, Ethiopia

Combined Effect of Carding Machine Process Parameters on Yarn Properties; Process Optimization

Kombinirani vpliv procesnih parametrov mikalnika s pokrovčki na lastnosti preje: optimiziranje procesov

Original scientific article/*Izvirni znanstveni članek*
Received/*Prispelo* 4-2021 • Accepted/*Sprejeto* 11-2021

Corresponding author/*Korespondenčni avtor:*
Million Ayele, Assist Prof
E-mail: milliti2000@gmail.com
ORCID ID: 0000-0002-0744-6246

Abstract
Yarn tensile properties, unevenness, and irregularities are the most important properties of the yarn quality parameters that determine the fabric's mechanical properties and appearance. In the current study, the combined effect of carding machine parameters (cylinder speed, flat speed, cylinder to flat setting, and taker-in speed) on yarn properties (yarn strength, elongation, unevenness, and total yarn imperfection) have been examined. In this research, 40 samples of open-end yarn were produced and each of them was tested for their strength, elongation, unevenness, and imperfection. Design-expert 7.0.0 software and Factorial designing have been employed to analyze the results. The results from statistical analysis have showed that increasing the gap between the cylinder and flat setting and increasing the taker-in speed increased yarn unevenness and increasing cylinder speed, flat speed, and taker-in speed increased total yarn imperfection significantly. Similarly, increasing the flat speed, cylinder speed, and taker-in speed as well as increasing the gap between the cylinder and flat reduced yarn strength and elongation significantly.
Keywords: yarn; process parameters, optimization, strength, unevenness, yarn imperfection

Izvleček
Natezne lastnosti, neenakomernost in nepravilnosti preje so najpomembnejši parametri kakovosti preje, ki vplivajo na njene mehanske lastnosti in videz. V raziskavi je bil proučen kombiniran učinek tehnoloških parametrov mikalnika (hitrosti mikalnega bobna, hitrosti mikalnih pokrovčkov, vzajemne nastavitve razdalje med mikalnim bobnom in pokrovčki in hitrosti dovajalnega valja) na lastnosti preje (trdnost, raztezek, neenakomernost in druge nepravilnosti). Za namen raziskave je bilo izdelanih 40 vzorcev rotorske preje. Izmerjeni so bili trdnost, raztezek, neenakomernost in t. i. skupne nepravilnosti preje. Za analizo rezultatov sta bili uporabljeni programski orodji Design-expert 7.0.0 in Factorial designing. Statistična analiza je pokazala, da sta povečanje razdalje med mikalnim bobnom in pokrovčki in povečanje hitrosti dovajalnega valja vplivala na povečanje neenakomernosti preje; povečanje hitrosti mikalnega bobna, hitrosti pokrovčkov in hitrosti dovajalnega valja pa je statistično pomembno vplivalo na skupne nepravilnosti preje. Podobno so povečanje hitrosti pokrovčkov mikalnika, hitrosti mikalnega bobna, hitrosti dovajalnega valja in tudi razdalja med mikalnim bobnom in pokrovčki vplivali na znatno zmanjšanje trdnosti in raztezka preje.
Ključne besede: preja, tehnološki parametri, optimizacija, trdnost, neenakomernost, nepravilnost preje

1 Introduction

The two well-known sayings, ‘the card is the heart of the spinning mill’ and ‘well-carded sliver is half spun’– demonstrate the enormous significance of carding for the end result of the spinning operation. The operation of the card shows the highest correlation to quality and also to productivity [1, 2]. Carding is the most important process in spinning. It contributes a lot to the quality of the yarn. Speeds (flat speed, taker-in speed, and cylinder speed) and settings (licker-in and feed plate, licker-in and under casing elements, cylinder and flat tops, between the cylinder and doffer, and so on) are process parameters which shall be controlled to produce good quality yarn with relatively low production cost.

Cylinder wire selection depends upon cylinder speed, the raw material to be processed, and the production rate. Wire front angle depends mainly on cylinder speed and the coefficient of raw material friction. The cylinder speed in turn depends upon the production rate. Higher production means that more working space for the fibre is required. It is the wire that keeps the fibre under its influence during carding operation [3]. Therefore, the space within the wire should be increased for higher production. Higher cylinder speed also increases the space required for the fibre. Therefore, a higher cylinder speed is required for higher production [4, 5].

The higher the cylinder speed is, the higher the centrifugal force created by the cylinder which tries to eject the fibre from the cylinder, along with the trash. Low front angle with too low cylinder speed and high frictional force will result in a bad quality of card sliver due to a decreased fibre transfer from the cylinder to the doffer [6, 7]. Hence, recycling of fibres will take place, which results in more neps and entanglements. The movement of the fibres towards the tip of the tooth coupled with centrifugal action demands an acute front angle to hold the fibre in place during carding [8].

The basic function of the doffer is to strip the fibres from the Cylinder. Licker-in plays a major role in opening the fibre tufts. A higher number of rows per inch gives better results. If the wire pitch is not sufficient, it can be compensated by increasing the licker-in speed. However, higher licker-in speeds for fine and long cotton will rupture the fibres [8]. The setting between the cylinder and doffer is the closest setting in the card. This setting mainly depends upon the cylinder speed, a hank of the delivered sliver, and the type of wire. If the setting between the cylinder and the doffer is very close, the wires will get polished, which will affect the fibre transfer. If the setting is too wide, the fibres will not be transferred to the doffer from the cylinder, hence the cylinder will get loaded. While processing synthetic fibres, cylinder loading will badly affect the yarn quality. The most critical setting in a carding machine is between the cylinder and flat tops. The closer the setting between the cylinder and flats is, the better the yarn quality is. Neps are directly affected by this setting. A very close setting increases flat waste. For processing cotton, the setting can be 0.25, 0.2, 0.2, 0.2, 0.2 mm [9]. Research results have showed that increasing the speed of the licker-in increased fibre rapture, yarn imperfection, and yarn hairiness and decreased single yarn strength. The increase in fibre rapture is due to a higher opening point-density, which results in a higher intensity of beating. The rise in fibre rapture increases short-fibre content, thus an increase in yarn imperfection and deteriorated single yarn strength [10]. However, the yarn unevenness (U %) and the card cleaning efficiency improve with higher licker-in speeds [11, 12].

Single yarn strength reduces with the increasing production rate of the carding machine. This is attributed to more fibre transfer efficiency leading to less fibre opening and parallelization in the sliver [13]. The neps level in the card sliver reduces when the point density of top flats is increased, minimizing the yarn imperfection. This is attributed to the intensified opening of neps [14].

The yarn unevenness increased with an increase in the card production rate due to poor carding and higher cylinder loading. The total yarn imperfections increase as the production rate increases and cylinder speed is reduced, attributed to more cylinder loading [15].

The purpose of this study is to research the combined effect of cylinder speed, flat speed, taker-in speed, and cylinder to flat setting on yarn properties like yarn strength, yarn imperfection yarn unevenness, and yarn elongation, which has not been studied so far.

2 Materials and methodology

2.1 Materials

Cotton fiber: 100% cotton fiber with the following property was used to manufacture the yarn (Table 1). The spinning consistency index (SCI) is a calculation for predicting the overall quality and spinnability of the cotton fiber.

2.2 Methods

2.2.1 Sliver production

Forty card slivers have been produced on a carding machine (C70), by varying the carding machine setting as stated in Table 2 at Alameda Textile share company, Adwa, Ethiopia. Forty 5,905 tex draw frame slivers (five-card slivers of each were made into one draw frame sliver) were produced on breaker and finisher draw frame machine with the model (RSB D45) and (SB D45), respectively. The machine setting of the draw frame was the same for the production of all slivers.

2.2.2 Yarn production

Forty 24.6 tex rotor spun yarn with twist of 860 m^{-1} were produced on a rotor spinning machine (R40 rotor spinning) at Almeda Textile share company, Almeda, Ethiopia. The feeding speed (0.425 m/min), opening roller speed (7500 min^{-1}), rotor speed (90,000 min^{-1}), and delivery speed (102 m/min) of rotor machine settings were kept constant during the production of all yarns.

2.2.3 Statistical optimization and experimental design of the fabric production process

Design expert 7.0.0 software was used in the optimizations of the yarn production. Design expert software was used as it is well-suited for engineering and science and it focuses on empirical design and optimization of the process parameters. The independent variables used were: cylinder speed, flat speed, cylinder to flat setting and taker-in speed of the carding machine, and the responses were: yarn strength (centinewton/tex), yarn elongation (%), yarn unevenness (Um %), and yarn total imperfections (in number) of the rotor spun yarn. 40 experiments (Table 2) were performed by design expert 7.0.0 software to optimize the machine setting. The statistical significance of the model and variables was determined by ANOVA at 5% significance level [16]. Yarn strength, unevenness, elongation, and imperfection (response factors) were analyzed by ANOVA and 3D response surface plotting.

2.2.4 Characterization of yarn property

To examine the combined effect of the independent variable of the carding machine (cylinder speed, flat speed, cylinder to flat setting, and taker-in speed) on yarn strength, unevenness, elongation, and total yarn imperfection, the following tests were conducted and analyzed:

(a) Effect of cylinder speed, flat speed, cylinder to flat setting, and taker-in speed on yarn unevenness

Unevenness and imperfection of the yarn were determined as per ASTM D1425/D1425M-14(2020). *Standard test method for evenness of textile strands using capacitance testing equipment*. Each sample was tested with five replicas and the average values were taken for analysis [17].

(b) Effect of cylinder speed, flat speed, cylinder to flat setting, and taker-in speed on yarn strength and elongation

Strength and elongation of the yarn were determined as per ASTM D1578-93(2016) *Standard test method for breaking strength of yarn in skein form*. Each sample was tested with five replicas and the average values were taken for analysis [18].

3 Results and discussions

3.1 Optimization of machine setting using factorial design

Yarn strength, elongation, unevenness, and imperfection are essential properties of yarn that must

Table 1: Cotton fiber specification for yarn production

Cotton	Spinning consistency index, SCI	Moisture content (%)	Upper half mean length, UHML (mm)	Uniformity index, UI (%)	Short fibre, SF (%)	Strength (cN/tex)	Elongation (%)
Avg.	82	5.1	25.96	76.7	14.7	23.2	6.2

be controlled to fulfill the standard required by the user [19, 20]. Yarn strength and elongation are important parameters in determining the durability and serviceability of the fabric made from the yarn and unevenness and imperfection are related to the appearance and ends down of yarn during yarn manufacturing [14]. The combined effect of flat speed, cylinder speed, cylinder to flat setting, and taker-in speed of the carding machine on the strength, elongation, unevenness, and imperfection of yarn has been studied and optimized using design expert 7.0.0 software and factorial design. The design allows random manufacturing of different samples, giving a chance to produce the same samples at different times, to avoid other nuisance factors. Generally, the process factors are designed to be at the carding section and are analyzed for their effects on rotor spun yarns.

3.2 Fitting the models

The dependent variables (strength, elongation, evenness, and imperfection) and independent variables (cylinder speed, flat speed, cylinder to flat setting, and taker-in speed) were examined to draw regression equations showing an empirical relationship between the tested variable and the machine settings in the actual units, which can predict the responses under the given range. Therefore, to determine the factor levels which yield optimum strength, elongation, evenness, and total yarn imperfection of the yarn, mathematical regression between dependent and independent variables (equations 1–4) were developed.

The final equations in terms of the actual factors generated by the factorial design were:

$$Yarn\ uneveness = +22.80 - 0.066 * A - 0.43 * B + 60.3 * C - 0.0186 * D - 0.025 * A * C + 8.3 * A * D - 0.056 * C * D \tag{1}$$

$$Yarn\ strength = +119.05 - 0.366 * A + 8.05 * B + 16.76 * C - 0.082 * D + 0.27\ A * C + 2.91424E - 004 * A * D - 00.126 * C * D \tag{2}$$

$$Yarn\ Elongation = +18.43 - 0.1327 * A + 39.09 * B + 101.06 * C - 0.0212 * D + 4.30303E - 004 * A * C + 1.38212E - 004 * A * D - 0.11 * C * D \tag{3}$$

$$Total\ yarn\ imperfection = +1535.466 + 2.47 * A + 450.83 * B + 3047.24 * C + 1.02 * D - 3.99 * A * C - 1.42121E - 003 * A * D - 1.41 * C * D \tag{4}$$

where A is cylinder speed, B is flat speed, C is cylinder to flat setting and D is taker-in speed.

3.3 Examination of model adequacy

Model individual significance and regression goodness was evaluated by ANOVA. In this research, ANOVA was used to analyze the selected model and model coefficient using 95% significant level. The regression terms and the model are said to be significant when the p-value is less than 5%. As shown in Tables 3 and 4, the model is significant statistically ($p < 0.05$) for the cylinder to flat setting and taker-in speed for unevenness, cylinder speed, flat speed and taker-in speed for total yarn imperfection and all independent variables (flat speed, cylinder speed, cylinder to flat setting and taker-in speed) were significant for the responses (yarn elongation and yarn strength).

3.4 Effect of flat speed, cylinder speed, cylinder to flat setting, and taker-in speed on yarn unevenness and total yarn imperfection

Unevenness and total imperfection of yarn are very important parameters of yarn which deals with variation in yarn count or fineness along the yarn length, negatively influencing the yarn as well as the fabric properties [21]. In the current study, the combined effects of cylinder speed, flat speed, cylinder to flat setting, and taker-in speed on yarn unevenness and yarn total imperfection have been

Table 2: Designed experiment and test results for rotor spun yarns

	Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2	Response 3	Response 4
Run	A: Cylinder speed (min^{-1})	B: Flat speed (m/min)	C:Cylinder to flat setting (mm)	D: Taker-in speed (min^{-1})	Yarn evenness, Um (%)	Yarn strength (cN/tex)	Elongation (%)	Total yarn imperfection, TYI
1	410	0.2	0.35	960	9.69	8.89	4.67	16
2	465	0.22	0.35	960	10.05	9.38	5.5	6
3	465	0.2	0.35	860	10.05	8.34	4.29	10
4	465	0.22	0.3	860	9.87	6.75	4.68	20
5	465	0.2	0.35	860	10.05	8.34	4.29	10
6	410	0.2	0.3	860	10.03	8.43	4.59	8
7	410	0.2	0.3	860	10.03	8.43	4.59	8
8	465	0.2	0.3	960	10.17	8.1	4.88	5
9	465	0.2	0.3	960	10.17	8.1	4.88	5
10	465	0.22	0.3	860	9.87	6.75	4.68	20
11	465	0.22	0.35	960	10.07	9.38	5.5	6
12	465	0.2	0.35	860	10.05	8.34	4.29	10
13	465	0.22	0.3	860	9.87	6.75	4.68	20
14	410	0.2	0.35	960	9.69	8.89	4.67	16
15	410	0.2	0.3	860	10.03	8.43	4.59	8
16	410	0.2	0.3	960	9.88	8.4	4.76	10
17	465	0.2	0.3	960	10.17	8.1	4.88	5
18	465	0.22	0.35	960	10.04	9.38	5.5	6
19	410	0.2	0.35	860	10.27	9.43	4.97	18
20	410	0.2	0.3	960	9.88	8.4	4.76	10
21	410	0.2	0.3	860	10.03	8.43	4.59	8
22	410	0.2	0.35	960	9.69	8.89	4.67	16
23	465	0.2	0.35	860	10.05	8.34	4.29	10
24	410	0.2	0.35	860	10.27	9.43	4.97	18
25	465	0.2	0.35	860	10.05	8.34	4.29	10
26	465	0.22	0.35	960	10.05	9.38	5.5	6
27	410	0.2	0.3	960	9.88	8.4	4.76	10
28	410	0.2	0.35	960	10.03	8.43	4.59	8
29	465	0.2	0.3	960	10.17	8.1	4.88	5
30	465	0.2	0.3	960	10.17	8.1	4.88	5
31	410	0.2	0.35	860	10.27	9.43	4.97	18
32	465	0.22	0.35	960	10.05	9.38	5.5	6
33	465	0.22	0.3	860	9.87	6.75	4.68	20
34	410	0.2	0.35	860	10.27	9.43	4.97	18
35	410	0.2	0.35	960	10.03	8.43	4.59	8
36	410	0.2	0.3	960	9.8	8.03	5.07	9
37	410	0.2	0.35	860	10.27	9.43	4.97	18
38	410	0.2	0.3	960	9.88	8.4	4.76	10
39	465	0.22	0.3	860	9.87	6.75	4.68	20
40	410	0.2	0.3	960	9.88	8.4	4.76	10

investigated. The ANOVA result in Table 3 revealed that increasing the gap between the cylinder and flat setting and increasing the taker-in speed increased yarn unevenness, and increasing the cylinder speed, flat speed, and taker-in speed decreased total yarn imperfection significantly. Figure 1 (a and b) also shows that the yarn irregularity decreases by decreasing the cylinder to flat setting and decreasing cylinder and taker-in speeds. This is due to the narrow cylinder-flats setting which augments the carding action and enhances the removal of short fibers. Increased speed of the taker-in rises fiber rapture and short fiber content. The increased speed of the main cylinder deters the action of the flats since their speed is comparatively insignificant and an increased centrifugal force on the fibers may disrupt their alignment.

As shown in Figure 1 (c and d), the total yarn imperfection also increases with decreasing cylinder and taker-in speeds, increasing flat speed, and wider cylinder-flat setting. When the speed of the cylinder is reduced, the fiber web is transferred to the doffer instead of spending additional time on the surface of the cylinder, which reduces the chance of additional carding time. This would increase the number of entangled fibers and neps not opened properly. Increased top flats and taker-in speeds, and a narrow cylinder-flat setting intensify the opening of tufts, fiber individualization, and longitudinal orientation and neps removal.

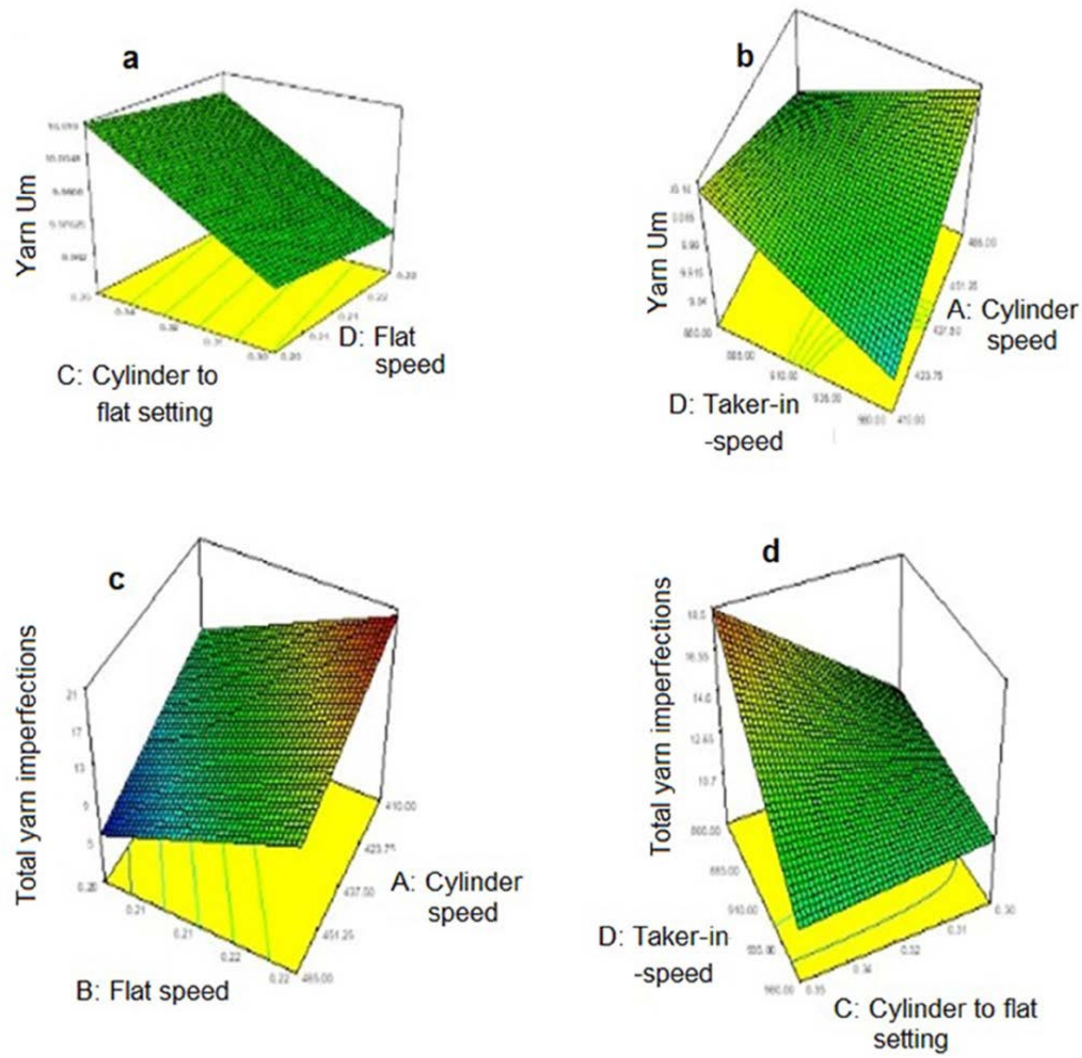


Figure 1: 3D response surface plots indicating effects: a) Cylinder to flat setting and flat speed on yarn Um, b) Taker-in speed and cylinder speed on yarn Um, c) Flat speed and cylinder speed on yarn total imperfection and d) Taker-in speed and cylinder to flat setting on yarn imperfection

Table 3: ANOVA Table for rotor spun yarn unevenness and total yarn imperfection

	Source	Sum of square	Df	Mean square	F-value	p-value
Yarn unevenness	Cylinder speed	1.598E-003	1	1.598E-003	0.2	< 0.6596
	Flat speed	2.153E-003	1	2.153E-003	0.27	< 0.6094
	Cylinder to flat setting	0.065	1	0.065	8.08	< 0.0077
	Taker-in speed	0.092	1	0.092	11.34	< 0.0020
Total yarn imperfection	Cylinder speed	214.8	1	214.8	85.55	< 0.0001
	Flat speed	201.16	1	201.16	82.92	< 0.0001
	Cylinder to flat setting	9.72	1	9.72	4.01	< 0.0537
	Taker-in speed	309.14	1	309.14	127.55	< 0.0001

3.5 Effect of flat speed, cylinder speed, cylinder to flat setting, and taker-in speed on yarn strength and elongation

Yarn strength and elongation are directly related to fabric durability and serviceability. Stronger yarn will result in better fabric durability and serviceability [22]. According to Table 4, the Factorial model used implies that the model is significant. Moreover, the effect of all main factors (cylinder speed, flat speed, cylinder to flat setting and taker-in speed) and the interaction between the cylinder and flat speeds, between cylinder and taker in speeds, the taker-in speed and flat top setting, were statistically significant on yarn strength and elongation. This implies that the above-stated main factors and their interaction affect yarn strength and elongation significantly. An increase of all independent variables reduced the yarn strength and elongation significantly. The yarn strength deteriorated with an increase in carding machine cylinder and taker-in speeds, and narrow cylinder-flat settings attributed to fiber rapture and deteriorated fiber strength. The yarn elongation increases with an increasing flat speed, cylinder speed, taker-in speed, and cylinder to flat setting. Lowered cylinder speeds attributed to intensified opening and greater short fiber removal. The longer and straighter the fibers, the higher is the twist consumption along the yarn axis. When all the produced twists are consumed along the fiber length, the elongation and strength is the greatest.

3.6 Comparison between the optimum and existing configurations

The optimum selected and existing configurations of the components are shown in Table 5. The optimum solution is selected considering yarn strength and elongation as the highest importance since the other properties are not out of range. The yarn strength and elongation are significantly improved without affecting the other properties. However, the software has generated thirty different configurations and corresponding results, allowing the

Table 4: ANOVA table for rotor spun yarn strength and yarn elongation

	Source	Sum of square	Df	Mean square	F-value	p-value
Yarn strength	Cylinder speed	2.3	1	2.3	200.13	< 0.0001
	Flat speed	0.064	1	0.0641	5.59	< 0.0243
	Cylinder to flat setting	11.11	1	11.11	965.9	< 0.0001
	Taker-in speed	1.53	1	1.53	133.31	< 0.0001
Yarn elongation	Cylinder speed	0.49	1	0.49	177.93	< 0.0001
	Flat speed	1.51	1	1.51	551.45	< 0.0001
	Cylinder to flat setting	0.12	1	0.12	42.94	< 0.0001
	Taker–in speed	1.04	1	1.04	380.96	< 0.0001

engineers to select the configurations and solutions according to their priorities.

3.7 Optimization of carding configurations

The optimum setup of the carding machine process parameters is shown in Table 5. The results show the rank of the setups based on their effect on rotor spun yarn (yarn Um%, yarn total imperfections, and Yarn strength & yarn elongation). Thus, the optimum setup of the carding machine parameters would be: cylinder speed (410 min^{-1}), top flat speed (0.20 m/min), cylinder to flat setting (0.35/0.30/0.275/0.25), and taker-in speed (861 min^{-1}). These setups of machine components produce a yarn having Yarn Um% (10.26%), yarn total imperfections (14) yarn strength (9.44 cN/tex), and yarn elongation (5.06%).

4 Conclusion

The cotton yarn has been used for fabric production for several years. The quality of the yarn is key parameter in the production of the yarn to manufacture durable and pleasant fabric. Yarn tensile properties, evenness, and yarn regularity are among the most important properties of the yarn that must be controlled during spinning.

This research aimed at obtaining the optimum carding machine setting to acquire the optimum result of yarn properties (yarn evenness, imperfection, strength, and elongation). The research results have shown that the narrow cylinder-flats setting augments the carding action and enhances the removal of short fibers and the total yarn imperfection increases with decreasing cylinder and taker-in speeds and flat speed. The yarn strength deteriorated with increasing cylinder speed, flat speed, and taker-in speeds, and narrow cylinder-flat settings attributed to fiber rapture and weakened fiber strength.

The yarn elongation increases with increasing flat speed and taker-in speeds and lowered cylinder speeds, attributed to intensified opening and greater short fiber removal. When all the produced twists are consumed along the fiber length, elongation and strength are maximized.

The optimum setup of the carding machine parameters to obtain the maximum possible yarn quality would be; cylinder speed (410 min^{-1}), top flat speed (0.20 m/min), cylinder to flat setting (0.35/0.30/0.275/0.25), and taker-in speed (861 min^{-1}). Future study will seek the effect of the carding machine setting on yarn productivity.

References

1. LAWRENCE, C.A. *Fundamentals of spun yarn technology*. Boca Raton : CRC Press, 2003.
2. LEE, M.E. *Mathematical models of the carding process: a thesis submitted for the degree of Doctor of Philosophy*. Oxford : Trinity College, University of Oxford, 2001.
3. BAGWAN, A.S., JADHAV, K. Card setting: a factor for controlling sliver quality and yarn. *Journal of Textile Science & Engineering,* 2016, **6**(2), 1–3, doi: 10.4172/2165-8064.1000246.
4. Textile Technology Spinning. Process parameters in carding [online]. Fibre2Fashion [accessed 14.12.2021]. Available on World Wide Web: <https://www.fibre2fashion.com/industry-article/3007/process-parameters-in-carding>.

Table 5: Comparison between the optimum and existing configurations

S/no	Configurations	Existing configuration	Optimum configuration
1	Cylinder speed (min^{-1})	415	410
2	Taker-in speed (min^{-1})	960	861
3	Flat speed (m/min)	0.20	0.20
4	Cylinder-flat gaps from entry to exit positions (mm)	0.30/0.275/0.25/0.2	0.35/0.30/0.25/0.2
Results	Yarn Um (%)	11	10.3
	Yarn total imperfections (ITI)	17	14
	Yarn strength (cN/tex)	7.75	9.4
	Yarn elongation (%)	4.79	5.1

5. CHELLAMANI, K.P., CHATTOPADHYAY, D., THANABAL, V. Influence of wire point density in cards and combers on neps in sliver and yarn quality. *Indian Journal of Fibre & Textile Research (IJFTR)*, 2003, **28**(1), 9–15, http://hdl.handle.net/123456789/24736.
6. SENGUPTA, A.K., Vijayaraghavan, N., SINGH, A. Studies on carding force between cylinder and flats in a card. Part I-effect of machine variables on carding force. *Indian Journal of Fibre & Textile Research (IJFTR)*, 1983, **8**(3), 59–63, http://nopr.niscair.res.in/handle/123456789/33071.
7. PENGZI, S. Discussion of cylinder speed of carding machine [J]. *Cotton Textile Technology*, 2001, **4**, 32–35.
8. KLEIN, Werner. *The Rieter manual of spinning. Vol. 1: technology of short-staple spinning.* Wintherthur : Rieter Machine Works, 2014.
9. USTER® STATISTICS: application handbook. Uster : Uster Technologies, 2013, https://pdf-coffee.com/application-handbook-uster-statistics-2013-pdf-free.html.
10. KOTB, N.A. Predicting yarn quality performance based on fibers types and yarn structure. *Life Science Journal*, 2012, **9**(3), 1009–1015.
11. *Advances in yarn spinning technology*. Edited by C.A. Lawrence. Oxford : Woodhead Publishing, 2010.
12. WANG X, Huang W, HUANG XB. A study on the formation of yarn hairiness. *The Journal of the Textile Institute,* 1999, **90**(4), 555–569, doi: 10.1080/00405000.1999.10750053.
13. LORD, E. *Manual of cotton spinning. Vol. 2. Part 1. The characteristics of raw cotton*. Manchester : Textile Institutte, 1961.
14. CHAUDHARI, V.D., KOLTE, P.P., DABERAO, A.M., CHANDURKAR, P.W. Effect of licker-in speed on yarn quality. *Melliand International*, 2017, **4**, 193–195.
15. CHAUDHARI, V.D., Kolte, P.P., CHAUDHARI, A.D. Effect of card delivery speed on ring yarn quality. *International Journal on Textile Engineering and Process*, 2017, **3**, 13–18.
16. MONTGOMERY, DOUGLAS, C. *Design and analysis of experiments*. Hoboken : John Wiley & Sons, 2017.
17. ASTM D1425/D1425M-14(2020). *Standard test method for evenness of textile strands using capacitance testing equipment.* ASTM International, 2020, 1–5, doi: 10.1520/D1425_D1425M-14R20.
18. ASTM D1578-93(2016). *Standard test method for breaking strength of yarn in skein form*. ASTM International, 2016, 1–8, doi: 10.1520/D1578-93R16.
19. SAMANTA, A.K. Effect of blend ratio on yarn evenness and imperfections characteristics of wool/polyester ring-spun yarn. *Indian Journal of Fibre & Textile Research (IJFTR),* 2014, **39**(1), 89–92, http://nopr.niscair.res.in/handle/123456789/27363.
20. *Process control and yarn quality in spinning*. Edited by G. Thilagavathi and T. Karthik. Boca Raton : CRC Press, 2016.
21. SLATER, K. Yarn evenness. *Textile Progress*, 1986, **14**(3–4), 1–90, doi: 10.1080/00405168608688901.
22. MEBRATE, M., GESSESSE, N., ZINABU, N. Effect of loom tension on mechanical properties of plain-woven cotton fabric. *Journal of Natural Fibers,* in presss, doi: 10.1080/15440478.2020.1776663.

Mong Hien Thi Nguyen[1], Tuong Quan Vo[1], Mai Huong Bui[1], Van Anh Pham[2]
[1] University of Technology-VNU–H CM, Faculty of Mechanical Engineering, Ho Chi Minh City, Vietnam
[2] Pham Van Dong University, Faculty of Engineering - Technology, Quang Ngai, Vietnam

The Algorithm to Automatically Extract Body Sizes and Shapes
Algoritem za samodejno pridobivanje podatkov o velikosti in telesnih oblikah

Original scientific article/*Izvirni znanstveni članek*
Received/*Prispelo* 3-2021 • Accepted/*Sprejeto* 12-2021

Corresponding author/*Korespondenčna avtorica:*
Mong Hien Thi Nguyen
E-mail: ntmhien14719@h cmut.edu.vn
ORCID ID: 0000-0002-5384-9775

Abstract
This study presents an algorithm to automatically extract the size and body shape of a 3D scanned model. The methods used in this research include factor analysis, linear regression equation, cluster analysis, and discriminant analysis. These are used to analyze the body's shape and choose the best primary dimensions for establishing the sizing system table. Authors use fuzzy logic to establish the mathematical model. In this model, the input variables are the inseam height and the neck girth measurements, and the output variables are the numbers of the human size coding and body shape. In addition, the rotation matrix and the optimal function are used to write an algorithm to estimate the neck girth and inseam measurements. Furthermore, a simple approach based on vertices and surface normal vector data, together with optimal searching, is adapted to estimate the primary dimensions. This estimation algorithm, combined with the fuzzy logic model, makes the automated process of extracting the size and body shape possible. The findings of the study suggest a new research method for quickly informing people about their body shape. This supports purchasing clothes and designing tailored clothing. The automatic algorithm will be very useful for buying clothes face-to-face or online.
Keywords: 3D scanner, extracting size, body shape, automatic, fuzzy logic

Izvleček
V prispevku je opisan algoritem za samodejno ugotavljanje velikosti in oblike telesa iz 3-D skeniranega modela. Za postavitev tabele dimenzioniranja so bile uporabljene metoda faktorske analize in linearna regresijska enačba ter analiza grozdov, diskriminantna analiza pa je bila uporabljena za analizo oblike telesa in izbiro najprimernejših primarnih dimenzij za načrtovanje ciljne funkcije. Metoda mehke logike je bila uporabljena za postavitev matematičnega modela z vhodnimi podatki, ki so spremenljive vrednosti primarnih dimenzij, in sicer sta to višina v razkoraku in obseg vratu. Te spremenljive vrednosti v velikostni tabeli kažejo na velikost in obliko telesa. Poleg tega se metoda rotacijske matrike združuje z optimalno funkcijo, ki se uporablja za pisanje algoritma pri oceni obsega vratu in dolžine v razkoraku. Preprost pristop, ki temelji na podatkih o vozliščih in površinskih normalnih vektorjih ter optimalnem iskanju, je prilagojen za oceno obsega vratu in višine v razkoraku. Te vrednosti bodo povezane z algoritmom mehke logike, ki se izvaja pri avtomatizaciji procesa. Študija podaja novo raziskovalno metodo za hitro določanje velikosti in oblike telesa posameznika za potrebe nakupovanja oblačil oz. oblikovanja oblačil. Ta samodejni algoritem je uporaben tako za kupce pri nakupu oblačil v trgovini ali na spletu kot tudi za izdelovalce oblačil za optimalno izbiro velikosti pri oblikovanju modela za potencialnega kupca.
Ključne besede: 3-D skener, določanje velikosti, oblika telesa, samodejno, mehka logika

1 Introduction

In the process of manufacturing garment technology, measurements have a significant impact on pattern making, establishing the sizing system tables, and analyzing the body shape. Much research has been done on measuring the human body with 3D scanners, which are widely used in the garment industry, such as creating avatars to illustrate the measurement method [1–4]. The authors extracted the measurements and saved body shapes using a 3D body scanner. In addition, 3D scanning also applies to assessing body movement and testing virtual samples [5]. This study was conducted on a sample consisting of 54 healthy males. Participants ranged in age from 9 - 37 years old, with an average height of 1.63–1.87 m with a weight range of 35–95kg. The 3D body scanner is used to test the correlation between the body and the virtual samples [6–9]. Updating anthropometric data will help garment and leather companies ensure product quality, so several studies have been aimed at extracting anthropometric data with 3D scanners [10–12]. The results of the 3D scanner are applied to classify the body shapes and are tested with the body dimensions [13–17]. Avatars of various sizes are created by automated 3D scanning. Avatars wear realistic clothes [18, 19]. This research aims at comparing the accuracy of the body's dimensions extracted by the 3D scanner to the real-life models. The first model wore underwear and clothes for scanning. The second model only wore underwear. The results show that the dimensions of the first model are larger than those of the second model [20]. In another study that used 3D scans to accurately determine the position of the bodies' necks for different types of neck shapes, the authors cut across the neck position on the 3D scanner. The results show that the neck girth has the shape of a spline curve [21]. Measurements extracted from a 3D scanner were applied to the design of a 2D pattern or when simulating avatars [22–25]. There are many other studies about designing 3D pattern to be converted to 2D patterns [26, 27]. This shows that body dimensions on 3D scanners are used for establishing sizing tables, analyzing body shapes, researching the fit of clothes, simulation of 3D patterns, designing patterns, or designing a virtual costume. No research has been conducted on the subject of automatically extracting the size and body shapes through primary dimensions.

2 Material and Methodology

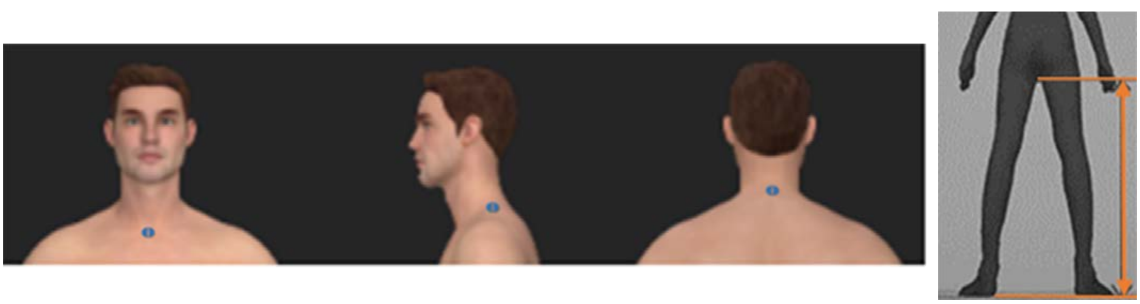
2.1 Material

Data to perform measurement extraction on the 3D body scanner were collected from a group of young men aged 18–25 years. The numbers of the samples are calculated by equation 1:

$$n = \frac{t^2 S^2}{m^2} \tag{1}$$

where n is a number of samples, S is standard deviation, m = 1, and t = 2.58. The total number of people attending this sampling measurement process is 542.

The dimensions to input into the equation for the extracted measurements are the neck girth and inseam height. These are two variables to put into the equation to get the fit size and body shape. The dimension of the neck girth is determined by 3 points: the front neck hollow point (a), the neck point that intersects the shoulder and the neck (b), and the point on the seventh cervical vertebra (c). The inseam height is determined from the bottom to the floor (d) (Figure 1), [28].



a) b) c) d)

Figure 1: The neck girth and inseam height

2.2 Methodology

The Matlab software uses the fuzzy logic method to extract the size and shape.
The interpolation and optimization method in the algorithm automatically extracts two primary dimensions and combines them with the fuzzy logic method to extract size and body shapes.

3 Results and Discussion

3.1 The size selection model

The mathematical model includes the sizing system data and two primary dimensions (Figure 2). These two primary dimensions are the inputs of the fuzzy controller. The first output is the size, and the second output is the size's shape. In every dimension group, the boundary conditions are different, such as 37.26 cm ≤ x1 ≤ 44.02 cm, and 62.5 cm ≤ x2 ≤ 87.5 cm. Subsequently, the results of the simulation are compared with the coding size and body shape in the size system given in Table 1. The values of the model's set parameters are the results of establishing the sizing system table. Two output variables are the coding size and sign shape. The range values of the two variables depend on the limitation and show differences between selecting the size by the traditional or the fuzzy method. There are five membership functions for input 1, and five membership functions for input 2.

3.2 The coding sizing system table

The coding sizing system table is added with two information columns: the coding size column and the inseam measurement column. The coding size column is numbered from 1-24. Inseam measurement is coded according to the group. Group A is 65 cm, group B is 70 cm, group C is 75 cm, group D is 80 cm and group E is 85 cm. In this table, every group has a different range of the inside leg measurement (Table 1). This range is the standard deviation of the inseam.

3.3 The Input-Output of the fuzzy logic

There are two variables for the input and two variables for the output of the fuzzy controller. Each input has multiple membership functions, such as the first input, which has five membership functions: very small, small, average, large, and very large (Figure 3a). The second input is the inseam dimension, which has five membership functions: very short, short, average, high, very high (Figure 3b).

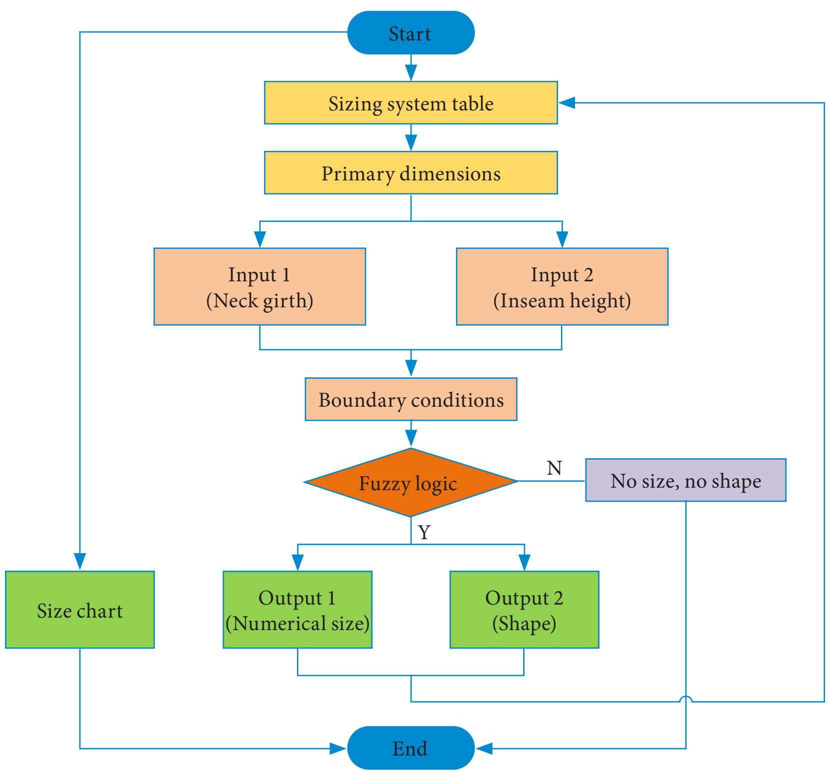
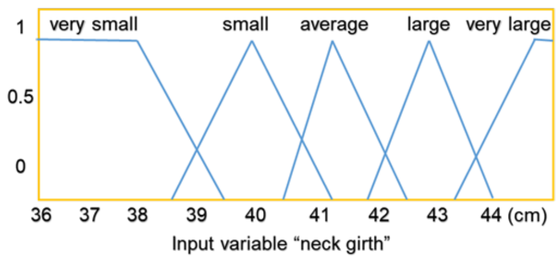


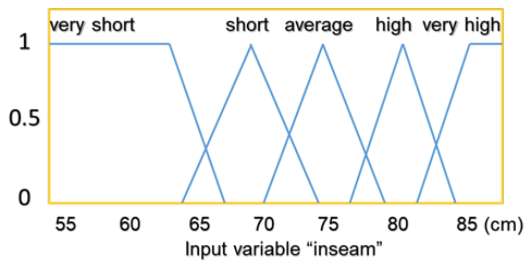
Figure 2: Selecting the size and the size's shape in fuzzy techniques

Table 1: The coding of groups

Group A: Inseam length [62.5–67.5 cm]					
Sign size	65/A1-1	71/A2-1	77/A3-2	83/A4-2	
Coding size	1	2	3	4	
Sign shape	1	1	2	2	
Neck girth (cm)	37.73	38.66	39.60	40.53	
Inseam (cm)	65	65	65	65	
Group B: Inseam length [67.5–72.5 cm]					
Sign size	65/B5-1	71/B6-1	77/B7-2	83/B8-2	89/B9-3
Coding size	5	6	7	8	9
Sign shape	1	1	2	2	3
Neck girth (cm)	38.25	39.18	40.12	41.05	41.99
Inseam (cm)	70	70	70	70	70
Group C: Inseam length [72.5–77.5 cm]					
Sign size	65/C10-1	71/C11-1	77/C12-2	83/C13-2	89/C14-4
Coding size	10	11	12	13	14
Sign shape	1	1	2	2	4
Neck girth (cm)	38.77	39.70	40.64	41.57	42.51
Inseam (cm)	75	75	75	75	75
Group D: Inseam length [77.5–82.5 cm]					
Sign size	65/D15-1	71/D16-1	77/D17-2	83/D18-2	89/D19-4
Coding size	15	16	17	18	19
Sign shape	1	1	2	2	4
Neck girth (cm)	39.29	40.22	41.16	42.09	43.03
Inseam (cm)	80	80	80	80	80
Group E: Inseam length [82.5–85 cm]					
Sign size	65/E20-1	71/E21-1	77/E22-2	83/E23-2	89/E24-4
Coding size	20	21	22	23	24
Sign shape	1	1	2	2	4
Neck girth (cm)	39.81	40.74	41.68	42.61	43.55
Inseam (cm)	85	85	85	85	85



a)



b)

Figure 3: a) The flowchart of membership functions of the first input, (b) The flowchart of the membership functions of the second input

Additionally, there are 24 output membership functions for the valve output 1 on the system (S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S12, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24), and the result is numerical 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24. In output 2, there are four shapes (trapezoid short leg, trapezoid tall height, oval, and rectangle). They are coded as 1, 2, 3, 4. These outputs are all constants (Table 2).

The curved plane of the fuzzy logic for the algorithm results (Figure 4) shows that there is a difference between the sizes of the four body shapes. It is perfectly consistent with the size chart setup results.

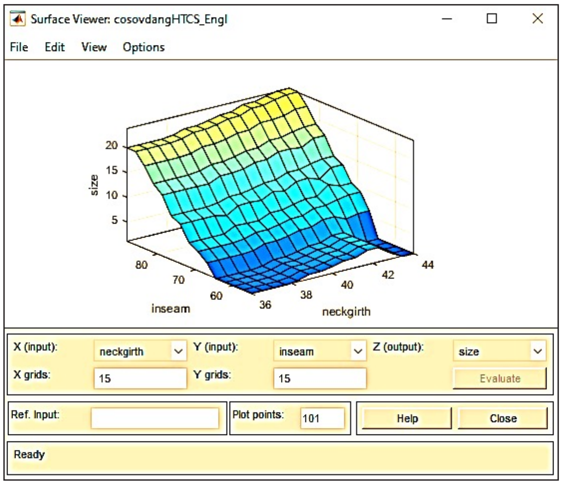


Figure 4: Curved plane fuzzy logic of the algorithm result

3.4 Flowchart for automatic extraction of size and body shape from 3D scanner data

The Matlab software uses the established size chart and built in algorithm to automatically estimate the neck girth and inseam, presented in flowchart form (Figure 5).

3.5 The process of automating the body scan to extract the size and body shape

The process of extracting the size and body shape is automated by using the algorithm to estimate the neck's girth and the inseam height measurements on the Matlab software. In this algorithm, the neck measurement process on the 3D scan database follows two schemes. In the options, a theta is the angle between the plane D and the floor; the D-plane contains the neck hollow and is perpendicular to the model's symmetry plane.

Table 2: The range of the parameters of membership functions for input variables

The first input					
Membership function	Parameter (cm)	Size	Membership function	Parameter (cm)	Size
Very small	[3726 37.73 38.20]	1	Large	[40.06 40.53 41]	4
	[37.78 38.25 38.72]	5		[40.58 41.05 41.52]	8
	[38.30 38.77 39.24]	10		[41.10 41.57 42.04]	13
	[38.82 39.29 39.76]	15		[41.61 42.09 42.56]	18
	[39.34 39.81 40.28]	20		[42.14 42.61 43.08]	23
	[37.26 38.77 40.28]			[40.06 41.57 43.08]	
Small	[38.19 38.66 39.13]	2	Very large	[41.52 41.99 42.46]	9
	[38.71 39.18 39.65]	6		[42.04 42.51 42.98]	14
	[39.23 39.70 40.17]	11		[42.56 43.03 43.50]	19
	[39.75 40.22 40.69]	16		[43.08 43.55 44.02]	24
	[40.27 40.74 41.21]	21		[41.52 42.77 44.02]	
	[38.19 39.7 41.21]		The second input		
Average	[39.13 39.60 40.07]	3	Membership function	Parameter (cm)	
	[39.65 40.12 40.59]	7	Very short	[60, 65 70]	
	[40.17 40.64 41.11]	12	Short	[65 70 75]	
	[40.69 41.16 41.63]	17	Average	[70 75 80]	
	[41.21 41.68 42.15]	22	High	[75 80 85]	
	[39.13 40.64 42.15]		Very high	[80 85 90]	

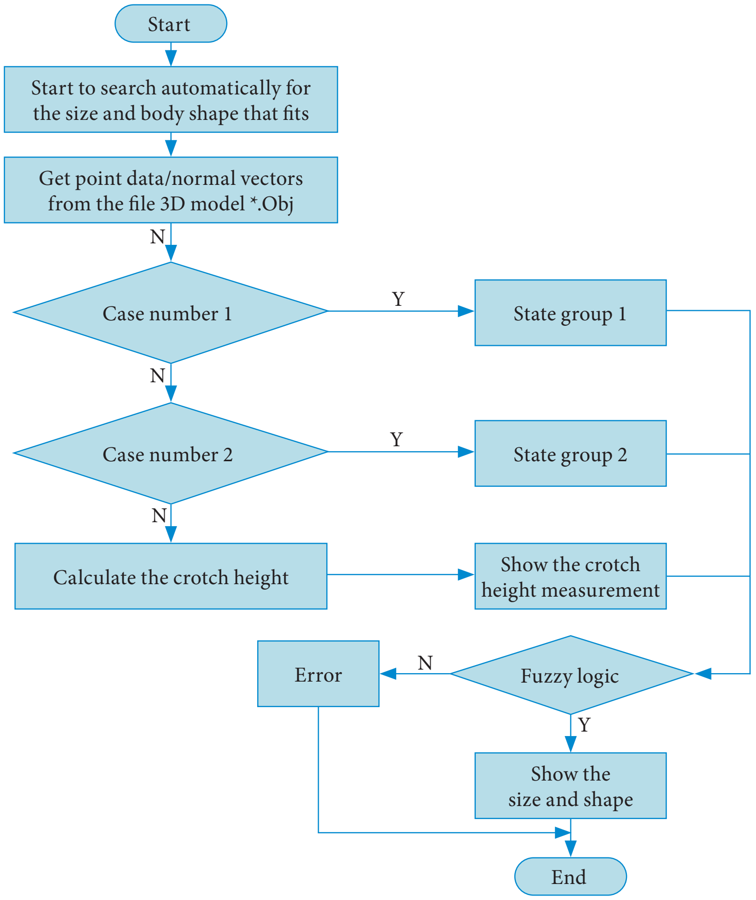
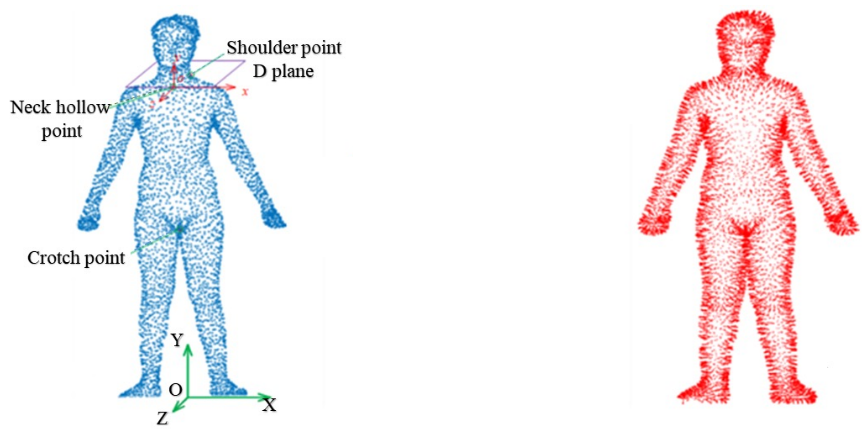


Figure 5: Automated flowchart for extracting size and body shape from 3D scanner data

Case 1: Estimate the neck girth by scanning the neck hollow

Using data from a 3D scanned object in *.obj file format (Figure 6), including three-dimensional position coordinates and corresponding unit normal vectors, a point on the face of object is defined by a vector , where v_x, v_y and v_z are components of the position vector, vn_x, vn_y and vn_z are elements of the normal vector with respect to the coordinate axes x, y, z. The process of estimating the neck girth is performed in 4 stages in the first case (Figure 7).



a) b)

Figure 6: a) The original coordinate system and the co-ordinate system at the cervical point, b) The point coordinates and vector on the scanned model are scanned

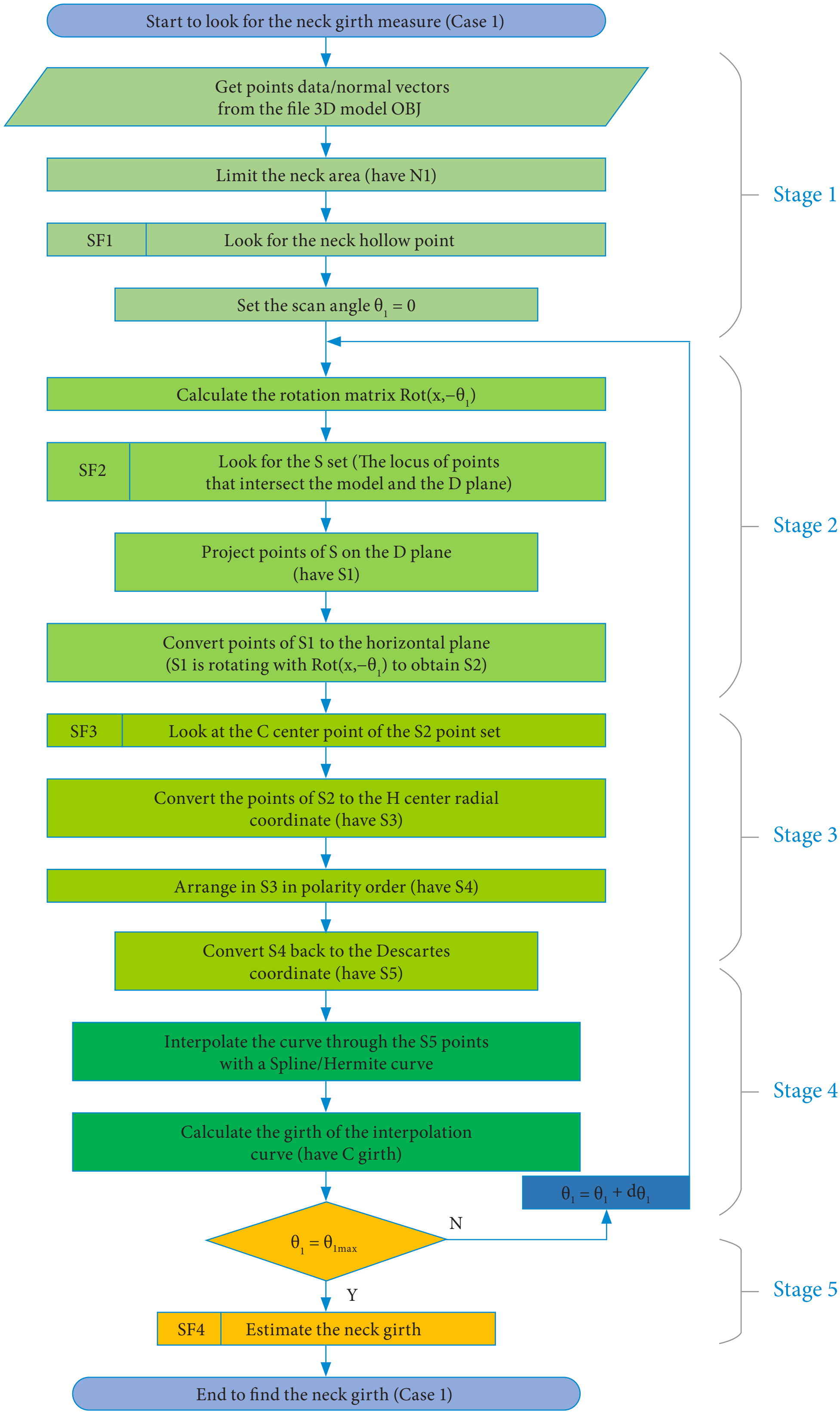


Figure 7: The algorithm to estimate the neck measurement according to case 1

Subfunctions for that algorithm in case 1 (Figure 8):

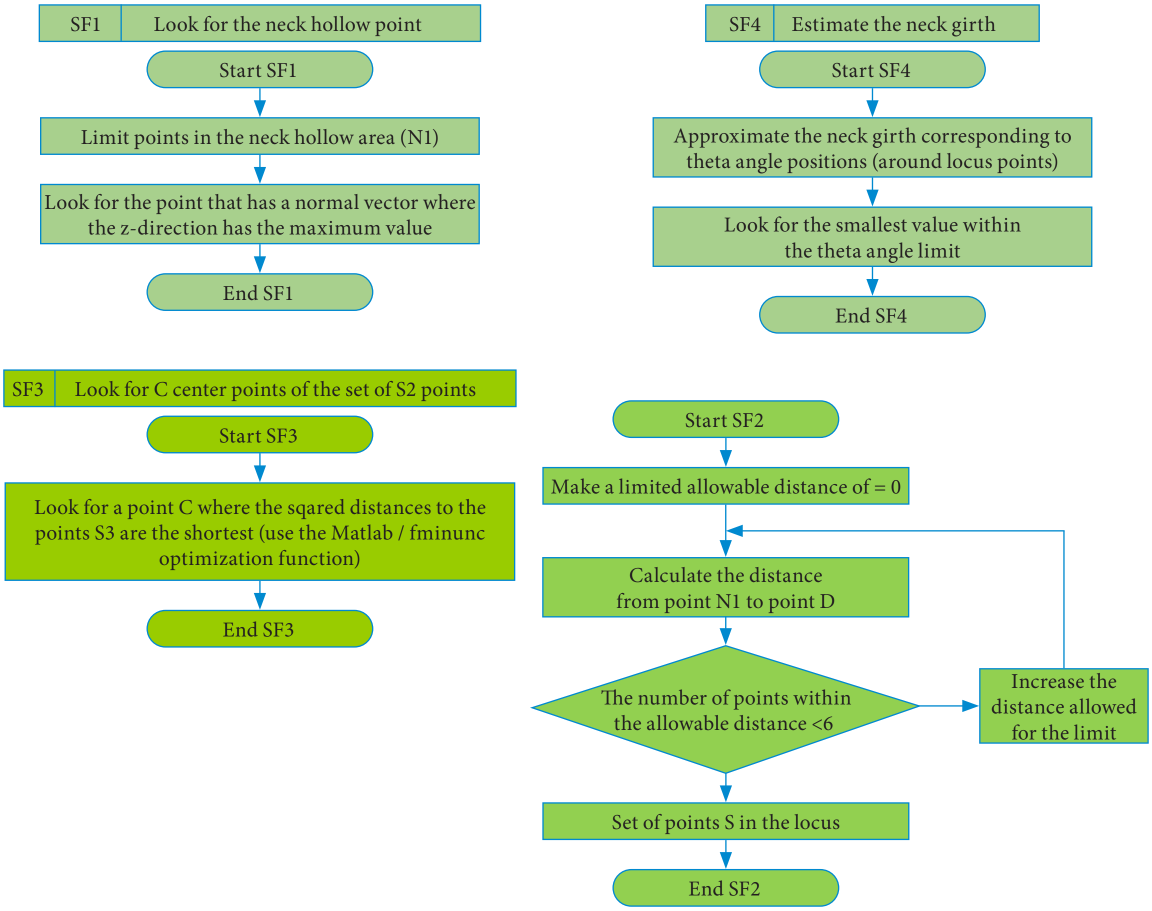


Figure 8: Subfunctions in case 1

The first stage: Prepare the scanned model data and the limited neck region data. Next, find the hollow point of the neck by searching for a point whose normal vector is closest to the normal vector of the xoy-plane. Assign the original scan angle (Figure 9).

The second stage: Calculate the rotation matrix.

Here:

$$Rot\ (x, -\theta_1) = \begin{bmatrix} R_1 & O \\ O & I \end{bmatrix}$$

$$R_1 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(-\theta_1) & -\sin(-\theta_1) \\ 0 & \sin(-\theta_1) & \cos(-\theta_1) \end{bmatrix}; O_{3\times3}, I_{3\times3};$$

where O_{3x3} and I_{3x3} are zero and unit matrixes. θ is the angle between the D-plane and the xoz-plane.

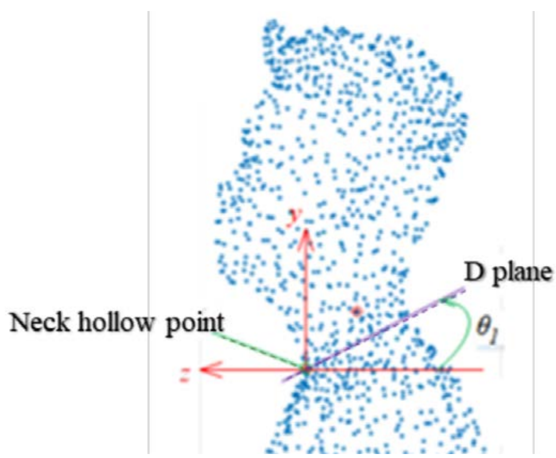


Figure 9: Limiting scanning data to the neck area

Then, search for the set S (a set of neighborhood points that intersect the 3D scan and the D plane). If you project the points of the set S onto the D-plane, you will get the set S1. Next, convert the points of S1 to the horizontal plane (by rotating S1 by Rot) (x_theta). This defines the set S2. When creating S2, the S2 phase assigns the distance to the limit point of O and then calculates the distance from the point N1 to the D plane, which gives the number of points within the allowable distance. When this condition is satisfied, a set of points S is given in the locus. Conversely, increase the allowable limit and recalculate the distance between N1 and the D-plane until you obtain a set of points S with an allowable distance. This procedure guarantees that the required number of fast points is always found within a flexible limit.

The third stage: Find the center C of the set of points of S2 set

Convert the points in S2 to the polar coordinates of the H center. This becomes S3. In the third stage, we look for a center C, whose sum of squared distances to the points S3 is smallest.

The fourth stage: Interpolate the neck curve

Corresponding to each point of θ_1, we interpolate a Spline/Hemite base on point set S5. Calculate the neck girth by measuring the length of the closed Spline, which has just been determined. Next, check if the scanning angle satisfies the conditions $\theta_1 = \theta_{1ma}$. If satisfied, proceed to stage 4. On the contrary, if $\theta_1 = \theta_1 + d\,\theta_1$, this section returns to the matrix calculation $Rot(x.\ \theta_1)$ and follow the stages until the correct results are obtained to finish the process of measuring in this phase.

The fifth stage: Estimate the neck girth

Average the perimeters of the necks corresponding to the changes in θ_1 angular positions, and then find the smallest value within the limit θ_1 corner.

Case 2: Estimation of neck girth by determining the shoulder peak point.

From the scanned 3D data, including point positions and normal vectors, we can calculate the neck girth at the D-plane position containing the shoulder peak point. However, to reduce geometric errors in calculations, we need to limit the n-region data (front side from the neck hollow point to the chin, back side from the seventh vertebra position to the neck) (Figure 10). In this case, implementation is done in five stages.

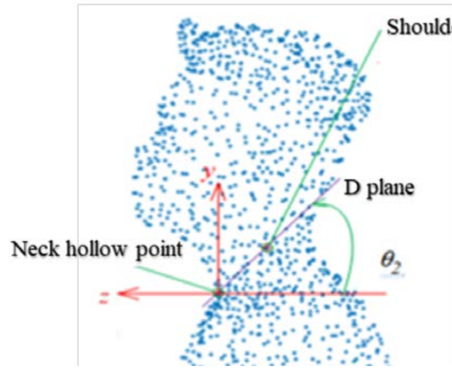


Figure 10: The neck range limit

The first stage: Find the neck hollow point

The steps of this stage include: First, prepare the 3D object data with the point coordinates and the corresponding unit normal vectors; second, limit search data to the neck region; third, find the neck-hollow point using the points whose unit normal vector is closest to that of the oxy-plane. Using a similar approach, we can easily find the peak point of the shoulder. Note that θ_2 is the angle between the D-plane and oxz-plane (see Figure 10). The D-plane contains the peak points of the ox-axis, the hollow neck and the shoulder. Finally, calculate the value of θ_2.

The second stage: Calculate the rotation matrix

$$Rot(x, -\theta_2) = \begin{bmatrix} R_2 & O \\ O & I \end{bmatrix}$$

where, $R_2 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(-\theta_2) & -\sin(-\theta_2) \\ 0 & \sin(-\theta_2) & \cos(-\theta_2) \end{bmatrix}$

Find a set of point, named S, which are neighbors of the intersection between the limit 3D model and the D2-plane. By projecting the points of set S on the D2-plane, we obtain a new set named S1. Then, by continuously converting the points of S1 to the horizontal plane through rotation transformation , we get the new set, denoted S2.

The third stage: Find the C center point of the S2 points

Convert the points of the S2 set to the H central coordinate will give the S3 set. Then, arrange the points into the S3 in the polar coordinate system order to obtain an S4.

The fourth stage: Interpolate neck curve

Interpolate the curve through the S5 points by the Spline/Hemite to get the closed neck value.

The fifth stage: Calculate the neck girth

The algorithm flowchart for estimating the neck measurement according to case 2 (Figure 11). Subfunctions for that algorithm are shown in Figure 12.

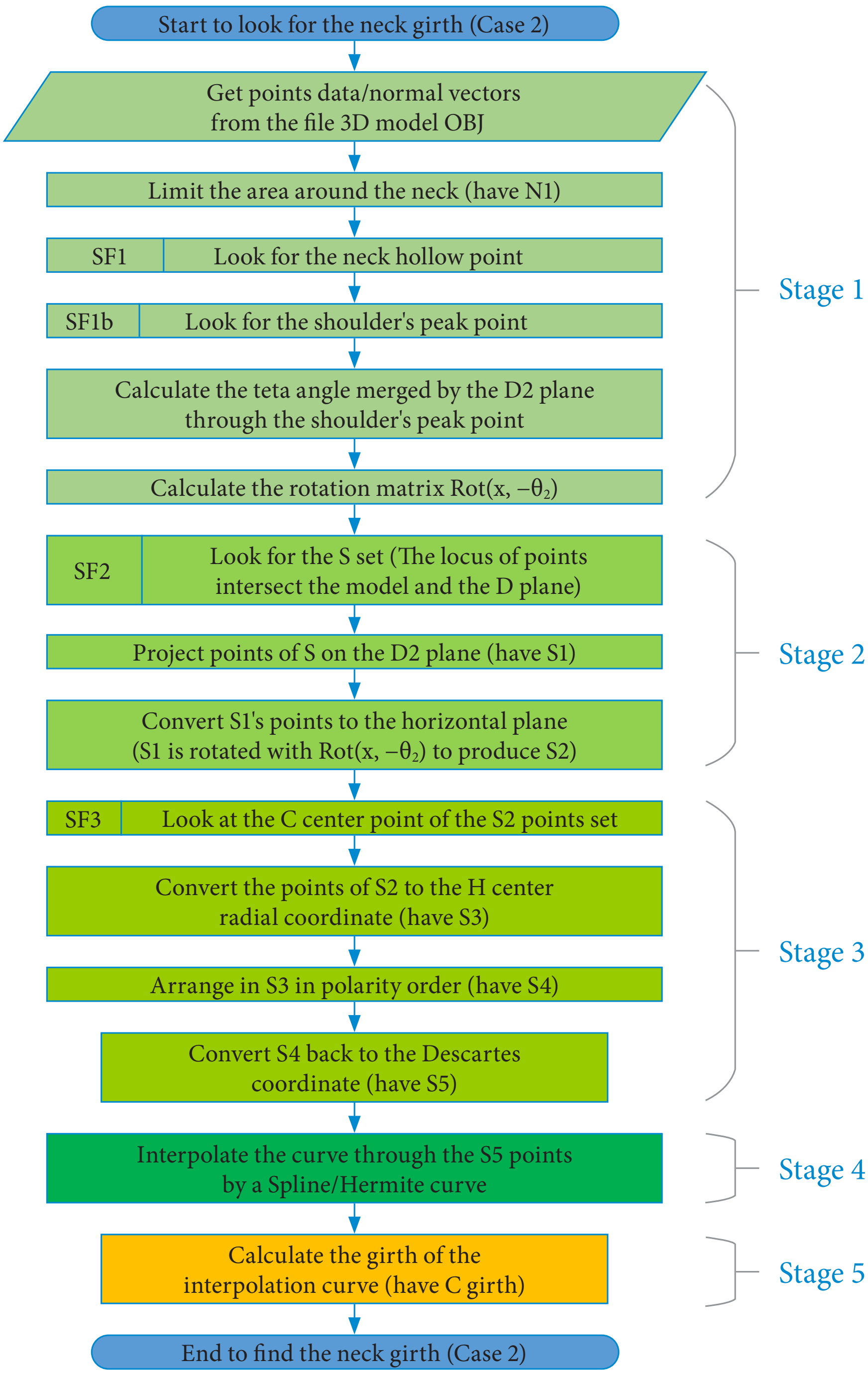


Figure 11: The algorithm to estimate the neck measurement according to case 2

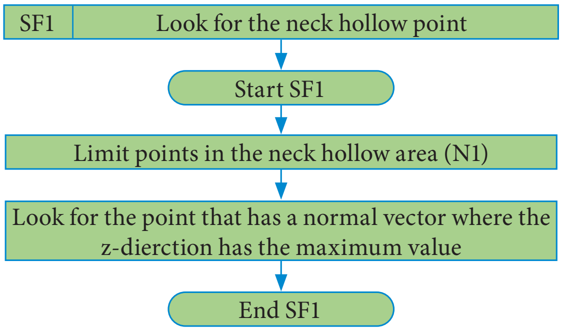


Figure 12: Subfunctions in case 2

Calculate the crotch height
The first stage is to limit the points within the inseam dimension range, then look for the point with the normal vector in the y-direction that has the maximum value. Next, the height from the floor to this maximum value is calculated (Figure 13). This is the inseam dimension height.

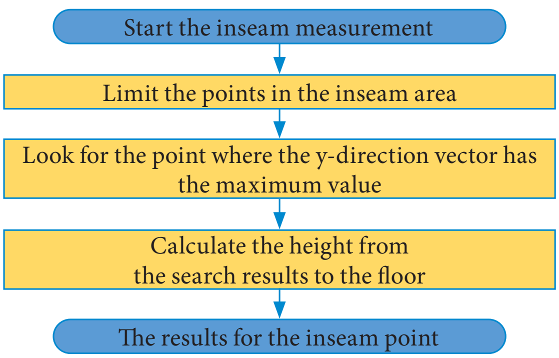


Figure 13: The algorithm to estimate the inseam dimension

3.6 The result of the automation for extracting the size and the shape

Table 3 shows the results of automating the neck size and inseam calculation algorithm used to extract size and body shape from 30 samples of 3D scan data, with two cases for neck girth estimation. Three different scenarios are shown. In the first example, the results are identical. The scanned samples have the correct standing posture; the chin is parallel to the ground and the head is kept straight (Figure 14, a). In the second instance, the results are different from the data because of an incorrect standing posture, such as the altered head position due to leaning forward or leaning back, a hunched back or skewed shoulders (Figure 14, b). In the third instance, the results show no size and no body shape group. For results with no size, this was mainly because the measurements of the neck girth were taken outside the boundary conditions, or due to an incorrect sample standing posture, or an altered head position due to leaning forward or backward, a hunched back, or skewed shoulders (Figure 14, c).

4 Conclusion

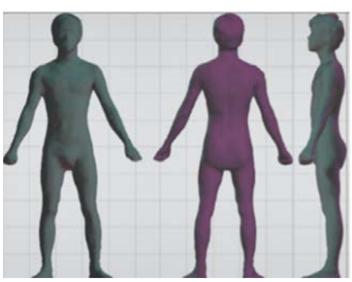
The study focused on using an automated system to extract the size and body shape in order to establish an algorithm model to extract them according to the simulation method on the Matlab software with two input variables, neck girth and inseam height. The first case is to perform a scan of the neck area through the scan angle created by the plane containing the neck hollow point and the plane of the floor. The second case is to scan the area of the neck through the scan angle created by the plane containing the shoulder's peak point intersecting the floor's plane. Also, the study analyzed the results of comparing the automation method with the simulation method. The results have shown that the scan samples with the correct scanning standing posture will give the same results. On the contrary, there are different results due to incorrect scanning positions of the sample. There are samples with small size deviations. The methods used in the research content of the paper include principal component analysis, factor analysis, and an ANOVA test to establish the sizing system tables. Moreover, the fuzzy logic technique is used to set up the numerical size extraction algorithm. The optimal search method is used to extract the size and body shape. The control test method is used to check the algorithm results again. This research proposes a way of selecting a fit size of garment for the human body. Furthermore, it may be applied to other fields in garment technology.

Acknowledgment

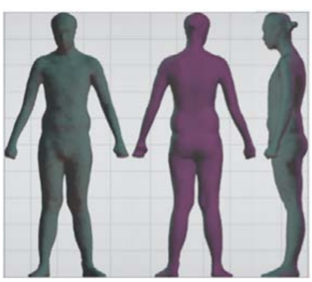
We acknowledge the support of time and facilities from Ho Chi Minh City University of Technology (HCMUT), VNU-HCM for this study.

Table 3: The results of dimensions and extraction body size/shape by the method of inputting data directly into the simulation program and the automating method

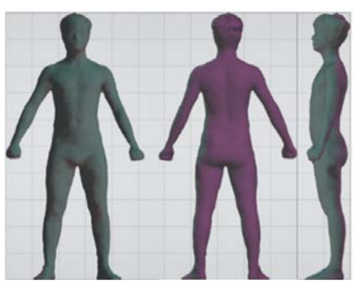
3D object	Neck size (3D Object)	Neck size (Case 1)	Neck size (Case 2)	Inseam (3D Object)	Inseam (automatic)	Size/Shape (Simulink)	Size/Shape (Case 1)	Size/Shape (Case 2)
1	40.05	40.57	36.33	67.6	67.51	7/2	7/2	0.5/0.5
2	40.8	41.01	39.18	71.03	71.34	8/2	8/2	6/1
3	40.34	37.28	35.76	71.26	71.73	7/2	0.5/0.5	0.5/0.5
4	39.08	39.59	37.82	70.48	70.49	6/1	6/1	5/1
5	43.27	44.56	41.19	73.38	74.19	0.5/0.5	0.5/0.5	13/2
6	37.77	37.48	36.05	68.55	68.78	0.5/0.5	0.5/0.5	0.5/0.5
7	38.84	39.22	46.31	72.86	73.48	10/1	10/1	0.5/0.5
8	41.16	40.04	41.85	74.76	75.59	13/2	11/1	13/2
9	38.85	42.82	38.82	70.88	69.6	6/1	0.5/0.5	6/1
10	44.09	38.85	31.26	80.24	79.94	0.5/0.5	15/1	0.5/0.5
11	46.13	38.53	40.05	73.09	72.90	0.5/0.5	10/1	11/1
12	42.84	51.91	35.11	75.05	74.98	14/4	0.5/0.5	0.5/0.5
13	40.81	40.47	38.26	75.96	75.67	12/2	12/2	0.5/0.5
14	37.99	41.01	35.22	70.19	70.22	5/1	8/2	0.5/0.5
15	41.85	36.35	37.32	75.7	76.26	13/2	0.5/0.5	0.5/0.5
16	41.06	40.92	40.92	71.68	71.99	8/2	8/2	0.5/0.5
17	36.1	49.61	37.21	83.85	83.21	0.5/0.5	0.5/0.5	0.5/0.5
18	38.44	38.46	39.36	73.3	72.72	10/1	10/1	11/1
19	38.83	39.14	37.6	77.54	77.63	15/1	15/1	0.5/0.5
20	41.31	41.53	40.63	73.58	73.35	13/2	13/2	12/2
21	38.14	38.87	51.26	73.55	74.14	0.5/0.5	10/1	0.5/0.5
22	40.05	40.42	39.38	79.16	79.2	16/1	16/1	15/1
23	46.84	33.67	37.05	71.59	72.6	0.5/0.5	0.5/0.5	0.5/0.5
24	36.35	35.95	34.75	65.45	65.55	0.5/0.5	0.5/0.5	0.5/0.5
25	43.01	46.37	43.03	77.32	77.18	0.5/0.5	0.5/0.5	0.5/0.5
26	37.54	36.78	38.8	69.81	69.88	0.5/0.5	0.5/0.5	6/1
27	38.65	34.61	41.72	75.42	75.75	10/1	0.5/0.5	13/2
28	43.03	36.5	45.29	81.64	83.25	19/4	0.5/0.5	0.5/0.5
29	38.95	32.31	33.67	72.14	72.62	6/1	0.5/0.5	0.5/0.5
30	41.2	45.39	41.43	72.58	72.69	13/2	0.5/0.5	13/2



a)



b)



c)

Figure 14: a) The sample's images in boundary conditions, b) The sample's images with a forward-leaning head, c) The sample's images in boundary conditions

References

1. YOON, Kyung, NAM, Yun Ja. Women's pant pattern design according to the style using 3D body scan data. *Journal of the Korean Society of Clothing and Textiles,* 2016, **40**(1), 97–113, doi: 10.5850/JKSCT.2016.40.1.97.
2. HWANG SHIN,Su-Jeong, CHANG, Hyo Jung and YOO, Sang-Mi. A case study of the 3D design process applied for customized art wears. *ITAA Annual Conference Proceedings,* 2016, **73**(1), 1–2, https://www.iastatedigitalpress.com/itaa/article/id/2998/.
3. PARKER, Christopher J., GILL, Simeon, HAYES, Stephen G. 3D body scanning has suitable reliability: an anthropometric investigation for garment construction. In *8th International Conference and Exhibition on 3D Body Scanning and Processing Technologies, Montreal, Canada*, 2017, 298–305, doi: 10.15221/17.298.
4. MA, Qianli, TANG, Siyu, PUJADES, Sergi, PONS-MOLL, Gerard, RANJAN, Anurag, BLACK Michael J. Dressing 3D humans using a conditional Mesh-VAE-GAN [online]. arXiv:1907.13615v1 [accessed 17. 11. 2021]. Available on World Wide Web: <https://www.researchgate.net/profile/Gerard-Pons-Moll/publication/334821694_Dressing_3D_Humans_using_a_Conditional_Mesh-VAE-GAN/links/5d768c1f4585151ee4ab0026/Dressing-3D-Humans-using-a-Conditional-Mesh-VAE-GAN.pdf>.
5. XIA, Likun, YANG, Jian, HAN, Tao, XU, Huiming, YANG, Qi, ZHAO, Yitian, WANG, Yongtian. A mobilized automatic human body measure system using neural network. *Multimedia Tools and Applications*, 2019, **78**, 11291–11311, doi: 10.1007/s11042-018-6645-6.
6. WANG, Zhen, ZHONG, Yue Qi, CHEN, Kai Jie, RUAN, Jia Yi, ZHU, Jin Cheng. 3D human body data acquisition and fit evaluation of clothing. *Advanced Materials Research,* 2014, **989–994**, 4161–4164, doi: 10.4028/www.scientific.net/amr.989-994.4161.
7. SAINT, Alexandre, SHABAYEK, Abd El Rahman, CHERENKOVA, Kseniya, GUSEV, Gleb, AOUADA, Djamila, OTTERSTEN, Björn. Bodyfitr: robust automatic 3D human body fitting. *IEEE International Conference on Image Processing (ICIP), Taipei, Taiwan,* 2019, 484–488, doi: 10.1109/ICIP.2019.8803819.
8. APEAGYEI, Phoebe, R. Application of 3D body scanning technology to human measurement for clothing Fit. *International Journal of Digital Content Technology and its Applications,* 2010, **4**(7), 58–68.
9. DEVANNE, Maxime, WANNOUS, Hazem, BERRETTI, Stefano, PALA, Pietro, DAOUDI, Mohamed, DEL BIMBO, Alberto. 3-D human action recognition by shape analysis of motion trajectories on riemannian manifold. *IEEE Transactions on Cybernetics*, 2015, **45**(7), 1340–1352, doi: 10.1109/TCYB.2014.2350774.
10. SPAHIU, T., SHEHI, E., PIPERI, E. Anthropometric studies: advanced 3D method for taking anthropometric data in Albania. *International Journal of Innovative Research in Science, Engineering and Technology*, 2015, **4**(4), 2136–2142, doi: 10.15680/IJIRSET.2015.0404065.
11. AZOUZ, Zouhour Ben, RIOUX, Marc, SHU, Chang, LEPAGE, Richard. Characterizing human shape variation using 3D anthropometric data. *The Visual Computer*, 2006, **22,** 302–314, doi: 10.1007/s00371-006-0006-6.
12. BALLESTER, Alfredo, PARRILLA, Eduardo, URIEL, Jordi, PIEROLA, Ana, ALEMANY, Sandra, NACHER, Beatriz, GONZALEZ, Jorge, GONZALEZ, Juan Carlos. 3D-Based resources fostering the analysis, use, and exploitation of available body anthropometric data. In *Proceedings of 5th International Conference on 3D Body Scanning Technologies, Lugano, Switzerland, 2014,* 237–247, doi: 10.15221/14.237.
13. COTTLE, Frederick S., ULRICH, Pamela V, TEEL, Karla P. Framework of understanding somatological constructs relative to the fit of apparel. In *Proceedings of 5th International Conference on 3D Body Scanning Technologies, Lugano, Switzerland, 2014,* 347–356, doi: 10.15221/14.347.
14. VURUSKAN, Arzu, BULGUN, Ender. Identification of female body shapes based on numerical evaluations. *International Journal of Clothing Science and Technology*, 2011, **23**(1), 46–60. doi: 10.1108/09556221111096732.
15. KIM, Soyoung, JEONG, Yeonhee, LEE, Yejin, HONG, Kyunghi. 3D pattern development of tight-fitting dress for an assymetrical female manikin. *Fibers and Polymers,* 2010, **11**, 142–146, doi: 10.1007/s12221-010-0142-5.
16. KIM, Sungmin. Analysis of human body surface shape using parametric design method. *International Journal of Clothing Science and*

Technology, 2015, **27**(3), 434–446, doi: 10.1108/IJCST-08-2014-0096.

17. CHEN, Chin-Man. Fit evaluation within the made-to-measure process. *International Journal of Clothing Science Technology*, 2007, **19**(2), 131–144, doi: 10.1108/09556220710725720.
18. D'APUZZO, Nicola. Recent advances in 3D full body scanning with applications to fashion and apparel. In *Optical 3-D Measurement Techniques IX, Vienna, Austria, 2009*. Edited by A. Gruen and H. Kahmen, 1-10, https://hometrica.ch/publ/2009_optical3d.pdf.
19. AGNIESZKA, Cichocka, PASCAL, Bruniaux, IWONA, Frydrych. 3D garment modelling - creation of a virtual mannequin of the human body. *FIBRES & TEXTILES in Eastern Europe,* 2014, **22**(6), 123–131, http://www.fibtex.lodz.pl/article1375.html.
20. KIM, Dong-Eun, LABAT, Karen, BYE, Elizabeth, SOHN, Myung Hee, RYAN, Karen. A study of scan garment accuracy and reliability. *The Journal of The Textile Institute*, 2015, **106**(8), 853–861, doi: 10.1080/00405000.2014.949502.
21. HUANG, H.Q., MOK, P Y., KWOK, Y.L., AU, J.S. Determination of 3D necklines from scanned human bodies. *Textile Research Journal*, 2011, **81**(7), 746–756, doi: 10.1177/0040517510387209.
22. LEE, Young-suk. Anthropometric data analysis for body shape modeling in Korean. *Korean Journal of Physical Anthropology*, 2013, **26**(2), 6169, doi: 10.11637/kjpa.2013.26.2.61.
23. TRANTIMINKAU. *Somatotype analysis and torso pattern development for Vietnamese women in 30s using 3D body scan data*. Ph.D. Thesis, 2012, http://www.riss.kr/link?id=T12939925&outLink=K.
24. CARRERE, C., ISTOOK, C., LITTLE, T., HONG, H., PLUMLEE, T. Automated garment development from body scan data. In *National Textile Center Annual Report*, November 2009, 1–9, https://silo.tips/download/national-textile-center-annual-report-november-2000-i00-s15-1.
25. KIM, Sungmin, PARK, Chang Kyu. Basic garment pattern generation using geometric modeling method. *International Journal of Clothing Science and Technology*, 2007, **19**(1), 7–17, doi: 10.1108/09556220710717017.
26. CICHOCKA, Agnieszka, BRUNIAUX, Pascal, KONCAR, Vladan. Modelling of virtual garment design in 3D. *Research Journal of Textile and Apparel*, 2007, **11**(4), 55–63, doi: 10.1108/RJTA-11-04-2007-B005.
27. PETRAK, S., MAHNIC, M., ROGALE, D. Impact of male body posture and shape on design and garment fit. *Fibres & Textiles in Eastern*, 2015, **6**(114), 150–158, doi: 10.5604/12303666.1167435.
28. ISO 8559-1:2017. *Size designation of clothes – Part 1: Anthropometric definitions for body measurement.* Geneva : International Organization for Standardization, 2017, 1–80.

SHORT INSTRUCTIONS FOR AUTHORS OF SCIENTIFIC ARTICLES

Scientific articles categories:

- **Original scientific article** is the first publication of original research results in such a form that the research can be repeated and conclusions verified. Scientific information must be demonstrated in such a way that the results are obtained with the same accuracy or within the limits of experimental errors as stated by the author, and that the accuracy of analyses the results are based on can be verified. An original scientific article is designed according to the IMRAD scheme (Introduction, Methods, Results and Discussion) for experimental research or in a descriptive way for descriptive scientific fields, where observations are given in a simple chronological order.
- **Review article** presents an overview of most recent works in a specific field with the purpose of summarizing, analysing, evaluating or synthesizing information that has already been published. This type of article brings new syntheses, new ideas and theories, and even new scientific examples. No scheme is prescribed for review article.
- **Short scientific article** is original scientific article where some elements of the IMRAD scheme have been omitted. It is a short report about finished original scientific work or work which is still in progress. Letters to the editor of scientific journals and short scientific notes are included in this category as well.

Language: The manuscript of submitted articles should be written in UK English and it is the authors responsibility to ensure the quality of the language.

Manuscript length: The manuscript should not exceed 30,000 characters without spacing.

Article submission: The texts should be submitted only in their electronic form in the format *.doc (or *docx) and in the format *.pdf (made in the computer program Adobe Acrobat) to the address: tekstilec@a.ntf.uni-lj.si. The name of the document should contain the date (year-month-day) and the surname of the corresponding author, e.g. 20140125Novak.docx. The articles proposed for a review need to have their figures and tables included in the text. The article can also be submitted through a cloud-based file transfer service, e.g. "WeTransfer" (www.wetransfer.com).

Publication requirements: All submitted articles are professionally, terminologically and editorially reviewed in accordance with the general professional and journalistic standards of the journal Tekstilec. Articles are reviewed by one or more reviewers and are accepted for publication on the basis of a positive review. If reviewers are not unanimous, the editorial board decides on further proceedings. The authors can propose to the editorial board the names of reviewers, whereas the editorial board then accepts or rejects the proposal. The reviewers' comments are sent to authors for them to complete and correct their manuscripts. The author is held fully responsible for the content of their work. Before the author sends their work for publication, they need to settle the issue on the content publication in line with the rules of the business or institution, respectively, they work at. When submitting the article, the authors have to fill in and sign the Copyright Statement (www.tekstilec.si), and send a copy to the editors by e-mail. They should keep the original for their own personal reference. The author commits themselves in the Copyright Statement that the manuscript they are submitting for publication in Tekstilec was not sent to any other journal for publication. When the work is going to be published depends on whether the manuscript meets the publication requirements and on the time reference the author is going to return the required changes or corrections to the editors.

Copyright corrections: The editors are going to send computer printouts for proofreading and correcting. It is the author's responsibility to proofread the article and send corrections as soon as possible. However, no greater changes or amendments to the text are allowed at this point.

Colour print: Colour print is performed only when this is necessary from the viewpoint of information comprehension, and upon agreement with the author and the editorial board.

More information on: www.tekstilec.si