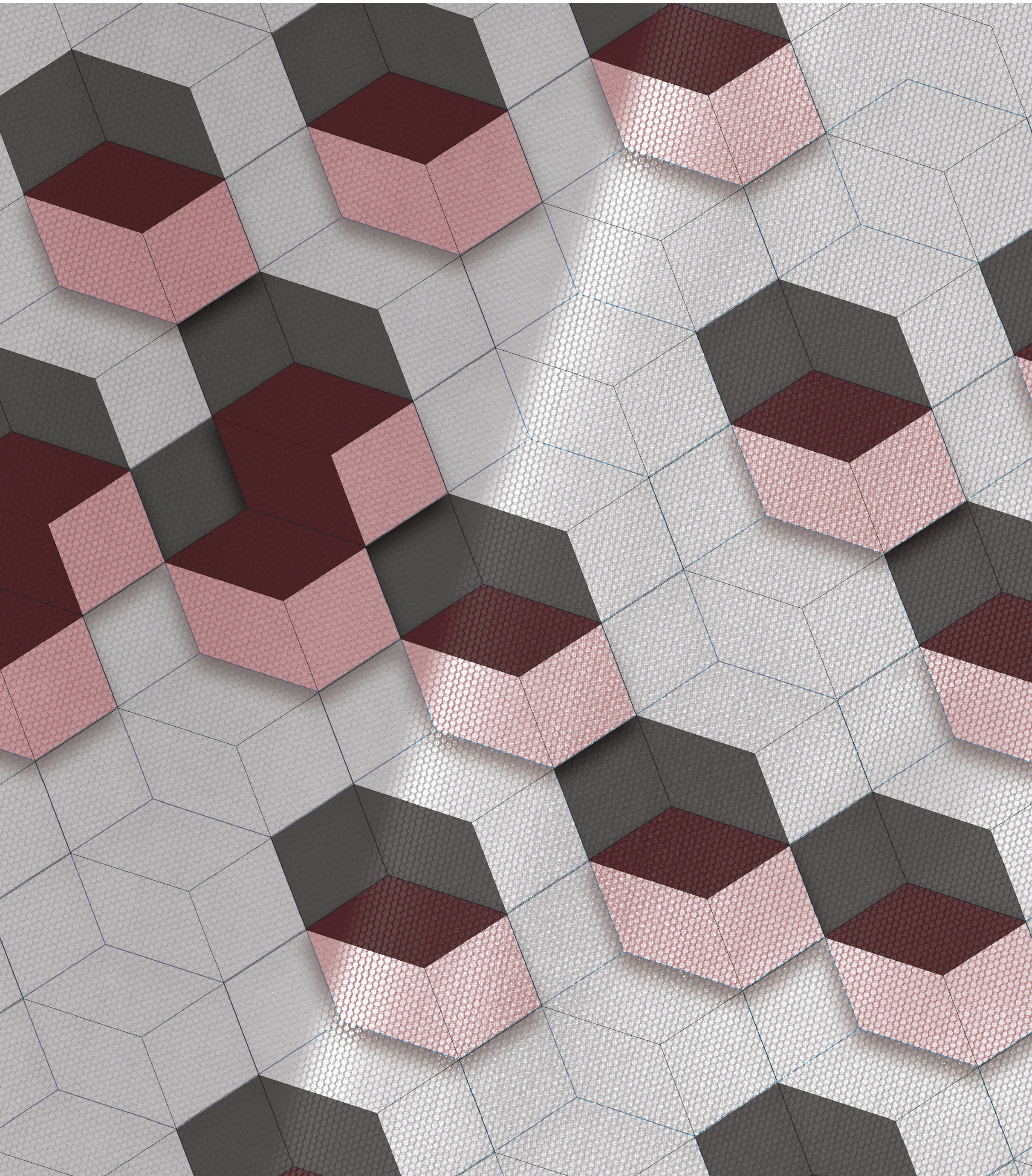
GLASILO SLOVENSKIH TEKSTILCEV • SLOVENE JOURNAL FOR TEXTILE AND CLOTHING TECHNOLOGY, DESIGN AND MARKETING

tekstilec

3/2020 • vol. 63 • 163–238
ISSN 0351-3386 (tiskano/printed)
ISSN 2350 - 3696 (elektronsko/online)
UDK 677 + 687 (05)



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SCOPUS/Elsevier (2018: Q3, SJR 0.16, Cite Score 0.45, SNIP 0.612 – v sodelovanju z/in cooperation with Leiden University's Center for Science & Technology Studies)
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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.

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
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Tisk / *Printed by* PRIMITUS, 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.

tekstılec VOLUME 63 • TEKSTILEC 3 2020 ISSN 0351-3386 (tiskano/printed)
UDK 677 + 687 (05)

SCIENTIFIC ARTICLES/ *Znanstveni članki*

Md. Mazharul Islam[1], Mohammad Abdul Jalil[2], Md. Shohan Parvez[2], Md. Mahbubul Haque[3]
[1] Northern University Bangladesh (NUB), Department of Textile Engineering, Dhaka, Bangladesh
[2] Khulna University of Engineering & Technology, Department of Textile Engineering, Khulna, Bangladesh
[3] Daffodil International University, Department of Textile Engineering, Dhaka, Bangladesh

Assessment of the Factors Affecting Apparel Pattern Grading Accuracy: Problems Identification and Recommendations

Ocena dejavnikov, ki vplivajo na natančnost ocenjevanja gradiranja oblačil: prepoznavanje težav in priporočila

Original Scientific Article/*Izvirni znanstveni članek*
Received/*Prispelo* 04-2020 • Accepted/*Sprejeto* 05-2020

Corresponding author/*Korespondenčni avtor:*
Md. Shohan Parvez
E-mail: shohan.parvez@te.kuet.ac.bd
ORCID: 0000-0003-3167-2240

Abstract
Grading is an inseparable part of producing multiple sized patterns in clothing production. From the inception of apparel manufacturing, various methods have been developed for precision pattern grading. Nevertheless, most conventional grading systems have some flaws. The objectives of this study were to analyse traditional grading systems, identify the factors responsible for pattern grading deficiencies and finally, recommend suggestions to minimise grading problems related to the use of CAD software. For the experiments, three different measurement sheets of different buyers were collected and combined into a single specification for better comparison. All garment patterns were then drawn and graded with varying parameters. Later on, measurements of graded patterns were analysed for grading accuracy. This study presents the factors responsible for grading deficiencies and how they can be minimised for higher precision grading for the better fitting of clothing and the prevention of garment sample rejection before bulk production.
Keywords: grading, CAD, pattern making, grading system, grading problems

Izvleček
Gradiranje je neločljiv del izdelave krojev oblačil različnih velikosti v proizvodnji oblačil. Od začetka industrijske izdelave oblačil so bile razvite različne metode za natančno gradiranje krojev oblačil. Kljub temu pa ima še vedno večina konvencionalnih sistemov gradiranja nekaj pomanjkljivosti. Cilji študije so bili analizirati tradicionalne sisteme gradiranja, ugotoviti dejavnike, ki vplivajo na pomanjkljivosti pri gradiranja krojev oblačil, in na koncu izdelati priporočila za zmanjšanje težav pri gradiranju z uporabo programske opreme CAD. Za eksperimente so bile pridobljene tri specifikacije mer različnih kupcev, združene v eno specifikacijo za lažjo primerjavo. Nato so bili konstruirani vsi krojni deli oblačila in gradirani z različnimi parametri. Kasneje so bile analizirane meritve gradiranih krojnih delov glede natančnosti gradiranja. Študija razkriva dejavnike pomanjkljivosti gradiranja in kako jih je mogoče minimalizirati, da dosežemo večjo natančnost gradiranja za boljše prileganje oblačil in preprečevanje zavrnitve oblačila pred masovno izdelavo.
Ključne besede: gradiranje, CAD, konstruiranje kroja oblačil, sistem gradiranja, problemi gradiranja

1 Introduction

Today's business policy for apparel manufacturers requires quick response systems that turn out a wide variety of products to meet customers' demand. In the apparel industry, in particular, stakeholders are trying to develop their current systems for new production techniques in order to keep pace with the rapid changes in the fashion and clothing industry [1]. The garment production process is separated into four main phases: designing and clothing pattern generation, fabric spreading and cutting, sewing and ironing and packing [2]. In order to manufacture apparel, proper sizing information is mandatory. Sizing is the process used to create a size chart of key body measurements for a range of apparel sizes [3]. For the mass production of ready-to-wear clothing, it is necessary to create all sized garments in the size range or sizes provided in the specification sheet. However, the creation of all size patterns is cumbersome and time-consuming. Pattern grading is traditionally used to create various sizes. Grading is a complex process used to create a complete set of patterns of different sizes contained in the size range. This is done by creating a pattern of a selected base size and then grading it up to create the largest sizes and down to create the smallest sizes. To grade a pattern, a set of grade rules are created or grading increment values are calculated. They are then inserted into the grade or cardinal point. Grade points or cardinal points are those points present at the perimeter of the pattern and distribute the changes in body dimension [4]. Generally, pattern grading is done to increase or decrease the dimension of the pattern to reproduce a complete set of patterns of different sizes in the size range to fit a group of people [5–6]. At present, with the mass the customisation of apparel sizing, advanced computer technology is being used widely [7]. Primarily for quick and precise production in apparel manufacturing, flexible computer-aided manufacturing systems are being applied to apparel manufacturing processes, such as apparel pattern making, grading, and marker making [8–9]. Computer-aided pattern making and grading are based on 2D and 3D CAD technologies. Individual patterns created using basic 2D pattern technologies apply grading and alternation rules [10]. In addition to individual patterns created by 3D CAD technology are 2D patterns that are flattened from a 3D body model, so that they reflect the human body type. However they have practical limitations, including the need to build a new 3D CAD system on the top of the existing apparel manufacturing process [11–13]. For that reason, 2D CAD technology is currently used in the apparel industry primarily for mass customisation. Although the 2D CAD system provides time-saving solutions, the latter are not free from limitations. The grade rule creation or grading increment calculation, which is used by all types of 2D apparel CAD to complete the grading process, is based on manual calculation and inputs [14]. Computerised pattern grading is the most precise and expedient method, but only when an accurate value is entered into the computer [6]. Nevertheless, there are many factors that influence grading and lead to grading deficiencies. The objectives of this study were to identify and analyse the reasons behind the inaccuracy and associated problems, while maintaining the required level of precision in garment pattern grading.

2 Methodology

2.1 Materials

For experiments, three different specification sheets (hereinafter: spec sheets) of different buyers were collected and then combined and drawn to a solitary sketch of a T-shirt (Figure 1 and Table 1), including all points of measures (POM) for the sake of easy comparison. For example, shoulder point can be calculated using three POMs in combination, if any two of "S", "SD and "AS" are given.

Table 1: Measurement points and descriptions of all three specification sheets

2.2 Methods

The patterns of T-shirts of specifications A, B and C were drawn and graded with varying parameters. The measurements of graded patterns were then checked for grading accuracy. The conventional grading system is based on the increment of the given measurement of apparel for different sizes using the Cartesian coordinate values of the grading increment. For example, if high point shoulder is increased by 2 cm, points H and G should increase by 2 cm in the direction of Y. For T-shirt Specs A, B and C, cardinal points represented by A, B, C, E, G, H for front and back and A, B, C, D, E, F, G for sleeve and the Cartesian coordinate values of the grading increment as (X, Y) are shown in Figure 2. The body parts of the three specification sheets have the same grading increment value despite differences in measurement location. In case of the sleeve, however, it is

Table 1: Measurement points and descriptions of all three specification sheets

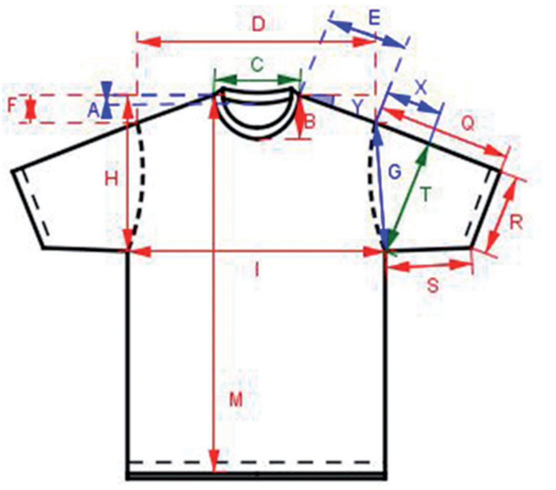


Figure 1: Combination of all measurement points of T-shirt

Points	Description	POMs
A	Back neck drop or depth	BND
B	Front neck drop or depth	FND
C	Neck width or opening	NW
D	Across shoulder width or shoulder to shoulder width	AS
E	Shoulder length	S
F	Shoulder drop or slant	SD
G	Armhole straight	AHS
H	Armscye depth	ASD
I	Half chest girth	HC
M	High point shoulder	HPS
Q	Sleeve length	SL
R	Sleeve opening	SO
S	Under sleeve length	US
T	Sleeve width or upper arm width	SW
X	Sleeve cap height	SCH
Y	Shoulder slant in degree	SSD

POM	Reference spec A					Reference spec B					Reference spec C				
	S	M	L	XL	XXL	S	M	L	XL	XXL	S	M	L	XL	XXL
BND	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
FND	8	8.5	9	9.5	10	8	8.5	9	9.5	10	8	8.5	9	9.5	10
NW	16	17	18	19	20	16	17	18	19	20	16	17	18	19	20
AS	-	-	-	-	-	45	48	51	54	57	45	48	51	54	57
S	15	16	17	18	19	15	16	17	18	19	-	-	-	-	-
SD	5	5	5	5	5	-	-	-	-	-	5	5	5	5	5
AHS	24	25	26	27	28	24	25	26	27	28	-	-	-	-	-
ASD	-	-	-	-	-	-	-	-	-	-	29	30	31	32	33
HC	48	51	54	57	60	48	51	54	57	60	48	51	54	57	60
HPS	70	72	74	76	78	70	72	74	76	78	70	72	74	76	78
SL	21	22	23	24	25	21	22	23	24	25	21	22	23	24	25
SO	18	19	20	21	22	18	19	20	21	22	18	19	20	21	22
US	14	14.5	15	15.5	16	-	-	-	-	-	-	-	-	-	-
SW	-	-	-	-	-	23	23.75	24.5	25.25	26	23	23.75	24.5	25.25	26
SCH	-	-	-	-	-	-	-	-	-	-	9.55	10.40	11.25	12.10	12.95

Note: All units are measured in cm. POM: Points of measure

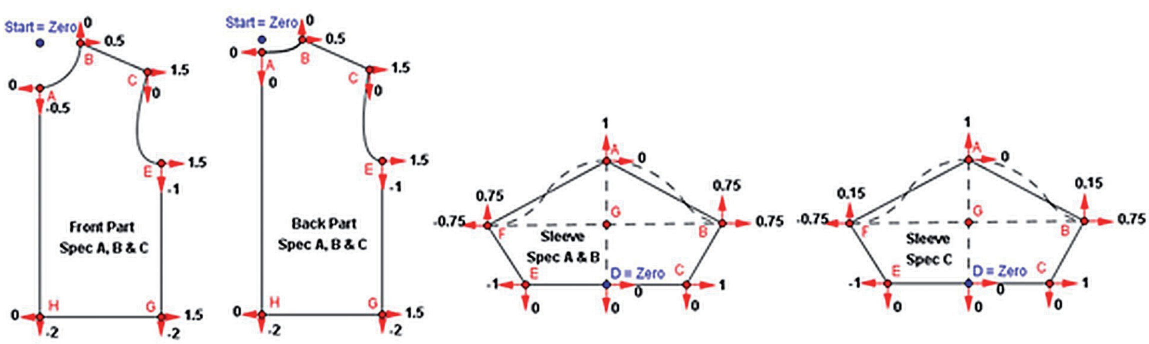


Figure 2: Cardinal points and Cartesian coordinate values of T-shirt spec A, B, and C

important to match the sleeve front and back curve with armhole front and back curve. For both Spec A and B, armhole straight is given, which is a diagonal measurement. In the case of Spec C, however, there are no diagonal measurements. Thus, the impact of the diagonal measurement is explained further in the following sections “presence of diagonal measurement” and “maintaining accuracy and matching of curve line”.

2.2.1 Presence of diagonal measurements

Some inclined or diagonal POMs (points of measure) create measurement errors in the traditional XY Cartesian coordinate apparel pattern grading system. In every grading textbook, different authors mention different types of shoulder seam grading [6, 15–18]. There is no consistency on how the textbook authors grade the shoulder [19]. For shoulder seam grading in the conventional method, some assumptions have been used. If across shoulder measurement and shoulder lengths are given (example: Reference Spec C), the X-axis increment is the change in half across shoulder and the Y-axis increment is the change in the shoulder length measurement plus the change in half neck width. However, if shoulder length and shoulder drop is given, the X-axis increment is the change in shoulder length plus the change in half neck width and the Y-axis increment is the change in the shoulder drop. It is thus assumed that shoulder length will increase the amount that is increased in the X or Y-axis. According to geometrical rules, however, any diagonal measurement will not increase for the amount of the increase in the X- or Y-axis. An experiment was conducted to check the effect of the diagonal measurement (e.g. shoulder length). For this experiment, patterns of the Spec A were graded using conventional Cartesian coordinate grading from the L size assumed as the base size. Bye et al. (2008) [20] confirmed that size 10 (medium size) was the optimum

Table 2: Length comparisons of Spec A

POMs	Measurement comparison	Size				
		S	M	L*	XL	XXL
Back neck drop	Length required	1.50	1.50	1.50	1.50	1.50
	Length acquired	1.50	1.50	1.50	1.50	1.50
Front neck drop	Length required	8.00	8.50	9.00	9.50	10.00
	Length acquired	8.00	8.50	9.00	9.50	10.00
Neck width	Length required	16.00	17.00	18.00	19.00	20.00
	Length acquired	16.00	17.00	18.00	19.00	20.00
Shoulder length	Length required	15.00	16.00	17.00	18.00	19.00
	Length acquired	15.10	16.05	17.00	17.96	18.92
Shoulder drop	Length required	5.00	5.00	5.00	5.00	5.00
	Length acquired	5.00	5.00	5.00	5.00	5.00
Armhole straight	Length required	24.00	25.00	26.00	27.00	28.00
	Length acquired	24.00	25.00	26.00	27.00	28.00
Sleeve arm hole straight	Length required	25.00	26.00	27.00	28.00	29.00
	Length acquired	25.42	26.21	27.00	27.79	28.58
Half chest	Length required	48.00	51.00	54.00	57.00	60.00
	Length acquired	48.00	51.00	54.00	57.00	60.00
High point shoulder	Length required	70.00	72.00	74.00	76.00	78.00
	Length acquired	70.00	72.00	74.00	76.00	78.00
Sleeve length	Length required	21.00	22.00	23.00	24.00	25.00
	Length acquired	21.00	22.00	23.00	24.00	25.00
Sleeve opening	Length required	18.00	19.00	20.00	21.00	22.00
	Length acquired	18.00	19.00	20.00	21.00	22.00
Under sleeve	Length required	14.00	14.50	15.00	15.50	16.00
	Length acquired	13.75	14.37	15.00	15.65	16.31

*Note: * = Base size, Black = Length required, Blue = Exactly same, Red = Deviation from original measurements. All units are measured in cm. POM: Points of measure.*

base size for grading patterns in the size range of 6–14. Size 10 was selected because a common practice in grading is to select a size approximately in the middle of the size range to be graded.

It can be concluded from Table 2 that all the horizontal and vertical line lengths are the same because they are plotted on the X and Y-axis respectively, as the computerised grading uses Cartesian coordinates. However, variations are found only in diagonal lines grading. Thus, diagonal measurements should be avoided as much as possible in the spec sheet because they cause grading deficiency.

2.2.2 Maintaining accuracy and matching of curve lines

The computer uses Cartesian coordinates where both points have X and Y values. It is therefore always a challenge how much they should move in both directions to get the accurate curve length.

The grading of a straight line is a simple process as the straight is defined by two endpoints in the computer Cartesian coordinates where both the points have X and Y values. So, it is possible to change the grading values (X, Y) in one or both points to get the desired length. However, the curve line grading is a complex process. Generally, the curve line is formed by connecting several points in the Cartesian coordinates location. When grade rules are applied to the endpoints of a curved edge, the program must mathematically determine how each internal curve and control point should move. The results can distort the curve. Again, in order to construct a well-made garment, the matching seam lines should be of the same length and the shape should not be distorted by the graded pattern pieces. During the grading of the curve line, the amount of change in X and Y directions to achieve the desired length of the curve is unknown. The grading increment must be adjusted several times until the desired curve length is achieved. For this experiment, all three spec-sheets (A, B and C) are selected and graded as specified, and the L size is chosen as a base size. Curve measurements are shown in Table 3.

From Table 3, it can be deduced that if horizontal and vertical measurements are given, curves automatically intersect with each other. If, however, diagonal measurements are given for instance like armhole straight, the pattern grader then has to calibrate the measurements until front and back armhole curve lengths match with the front and back sleeve curve lengths.

The measurements should be checked and the grading increment should be adjusted until the required curve lengths are achieved.

Table 3: Comparison of curve lengths after conventional grading of different spec

Combination of POMs	POMs direction	Reference spec.	Measurement	Size					Unit
				S	M	L*	XL	XXL	
If SL, SO, AHS & US are given	Vertical, Horizontal, Diagonal & Diagonal	A	Front armhole curve	25.34	26.40	27.45	28.50	29.56	cm
			Front sleeve curve	25.84	26.64	27.45	28.25	29.06	
			Difference	+0.50	+0.24	0.00	-0.25	-0.50	
			Back armhole curve	25.25	26.30	27.35	28.40	29.45	
			Back sleeve curve	25.75	26.55	27.35	28.15	28.95	
			Difference	+0.50	+0.25	0.00	-0.25	-0.50	
If SL, SO, AHS & SW are given	Vertical, Horizontal, Diagonal& Horizontal	B	Front armhole curve	25.39	26.44	27.50	28.56	29.61	
			Front sleeve curve	25.90	26.70	27.50	28.30	29.10	
			Difference	+0.51	+0.26	0.00	-0.26	-0.51	
			Back armhole curve	25.34	26.40	27.45	28.50	29.56	
			Back sleeve curve	25.85	26.65	27.45	28.25	29.05	
			Difference	+0.51	+0.25	0.00	-0.25	-0.51	
If SL, SO, SCH& SW are given	Vertical, Horizontal, Vertical & Horizontal	C	Front armhole curve	25.39	26.45	27.50	28.55	29.61	
			Front sleeve curve	25.40	26.45	27.50	28.56	29.63	
			Difference	+0.01	0.00	0.00	+0.01	+0.02	
			Back armhole curve	25.35	26.40	27.45	28.50	29.56	
			Back sleeve curve	25.36	26.40	27.45	28.51	29.58	
			Difference	+0.01	0.00	0.00	+0.01	+0.02	

*Note: * = Base size, Black = Length required, Blue = Exactly same, Green = Within tolerance, Red = Over tolerance limit (Explain tolerance limits) Tolerance = ± 0.20 cm, Units = Measured in cm*

2.2.3 Selection of base size in grading

If we choose jumping sizes rather than moving gradually from one size to another, some measurements often exceed the tolerance limit.

The selection of the base size also has an influence over the pattern grading accuracy. Basically, there are three methods of recording the growth of the pattern:

- **Method 1:** Progressive increment of the base size (from smallest to the largest size).
- **Method 2:** Progressive increment or decrement of the base size to acquire all the sizes from the smallest to the largest.
- **Method 3:** Digressive decrement of the base size to the smallest size.

After evaluating the graded measurement from Table 4, it can be deduced that horizontal and vertical measurements do not change even if the base size changes. The reasoning behind is that they were plotted along X and Y axis of Cartesian coordinates. However, inclined measurements of a graded pattern are inconsistent and sometimes exceed the tolerance limit if the base size changes. Additionally, greater variations are found from the smallest and to the largest base size. So, if the middle size from the provided size chart is considered as a base size (e.g. L as base size, if the size chart contains S, M, L, XL and XXL size), the errors can be minimised as they can have both positive and negative direction towards the given tolerance. So, the deficiencies of inclined measurements grading can be minimized by selecting the middle size as the base size.

Another reason for the selection of the base size is the presence of breakpoint. The breakpoint of a size chart is such a measurement upon whose increment, graded pattern varies. For instance, if mentioned half-chest is 46, 48, 50, 52, 55, and 58 (units in cm) respectively for six sizes; the base size should be the size which contains half-chest 52 (units in cm), so that both sides' measurement differences would be the same. It is recommended to grade from middle size to all sizes to reduce measurement errors if diagonal measurements are given.

2.2.4 Presence of higher number of sizes

Diagonal measurements relating to grading error increase as the number of sizes in the spec sheet increases. If the grading is done to get the extreme sizes, then the design, drape and fit of the garment

Table 4: Length Comparisons of diagonal measurements of T-shirt Spec A

POMs	Size	Measurement comparison							
		Length required	Tol (±)	S→XXL		S←L→XXL		XXL→S	
				Got	Error	Got	Error	Got	Error
Shoulder	S	15	0.15	15.00*	0.00	15.10	+0.1	15.18	+0.18
	M	16		15.95	-0.05	16.05	+0.05	16.13	+0.13
	L	17		16.90	-0.10	17.00*	0.00	17.08	+0.08
	XL	18		17.86	-0.14	17.96	-0.04	18.04	+0.04
	XXL	19		18.82	-0.18	18.92	-0.08	19.00*	0.00
Armhole straight	S	24	0.30	24.00*	0.00	24.00	0.00	24.01	+0.01
	M	25		25.00	0.00	25.00	0.00	25.01	+0.01
	L	26		25.99	-0.01	26.00*	0.00	26.00	0.00
	XL	27		26.99	-0.01	27.00	0.00	27.00	0.00
	XXL	28		27.99	-0.01	28.00	0.00	28.00*	0.00
Sleeve armhole straight	S	25	0.30	25.00*	0.00	25.42	+0.42	25.84	+0.84
	M	26		25.79	-0.21	26.21	+0.21	26.63	+0.63
	L	27		26.58	-0.42	27.00*	0.00	27.42	+0.42
	XL	28		27.37	-0.63	27.79	-0.21	28.21	+0.21
	XXL	29		28.16	-0.84	28.58	-0.42	29.00*	0.00
Under sleeve	S	14	0.25	14.00*	0.00	13.82	-0.18	13.63	-0.37
	M	14.5		14.60	+0.10	14.40	-0.10	14.20	-0.30
	L	15		15.21	+0.21	15.00*	0.00	14.78	-0.22
	XL	15.5		15.84	+0.34	15.62	+0.12	15.38	-0.12
	XXL	16		16.48	+0.48	16.25	+0.25	16.00*	0.00

*Note: * = Base size, Black = Length required, Blue = Exactly same, Green = Within tolerance, Red = Over tolerance limit, Units: Measured in 'cm'.*

changes as well [6, 21, 22]. Moore et al. (2001) [23] recommend that no more than five sizes (two larger, two smaller and one base size) should be graded from the base size together using a simplified grading system; otherwise the average size range would then require multiple base sizes. A pattern should not be graded more than two sizes from the base size, so that the visual appearance remains unaffected [21].

Table 5: Measurements of two spec sheets having two different size numbers

POMs	Reference spec A					Reference spec D							Unit
	S	M	L	XL	XXL	XS	S	M	L	XL	XXL	3XL	
BND	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	cm
FND	8.00	8.50	9.00	9.50	10.00	7.50	8.00	8.50	9.00	9.50	10.00	10.50	
NW	16.00	17.00	18.00	19.00	20.00	15.00	16.00	17.00	18.00	19.00	20.00	21.00	
S	15.00	16.00	17.00	18.00	19.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00	
SD	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
AHS	24.00	25.00	26.00	27.00	28.00	23.00	24.00	25.00	26.00	27.00	28.00	29.00	
HC	48.00	51.00	54.00	57.00	60.00	45.00	48.00	51.00	54.00	57.00	60.00	63.00	
HPS	70.00	72.00	74.00	76.00	78.00	68.00	70.00	72.00	74.00	76.00	78.00	80.00	
SL	21.00	22.00	23.00	24.00	25.00	20.00	21.00	22.00	23.00	24.00	25.00	26.00	
SO	18.00	19.00	20.00	21.00	22.00	17.00	18.00	19.00	20.00	21.00	22.00	23.00	
US	14.00	14.50	15.00	15.50	16.00	13.50	14.00	14.50	15.00	15.50	16.00	16.50	

Table 6: Length Comparisons of T-shirt Spec A and D (diagonal measurements)

Points of Measures	Spec	Measurement comparison	Size							Tol (±)
			XS	S	M	L	XL	XXL	3XL	
Shoulder length	A	Length required	-	15.00	16.00	17.00	18.00	19.00	-	0.15 cm
		Length acquired	-	15.10	16.05	17.00*	17.96	18.92	-	
		Error	-	+0.10	+0.05	0.00	-0.04	-0.08	-	
	D	Length required	14.00	15.00	16.00	17.00	18.00	19.00	20.00	
		Length acquired	14.16	15.10	16.05	17.00*	17.96	18.92	19.89	
		Error	+0.16	+0.10	+0.05	0.00	-0.04	-0.08	-0.11	
Armhole straight	A	Length required	-	24.00	25.00	26.00	27.00	28.00	-	0.30 cm
		Length acquired	-	24.01	25.01	26.00*	27.00	28.00	-	
		Error	-	+0.01	+0.01	0.00	0.00	0.00	-	
	D	Length required	23.00	24.00	25.00	26.00	27.00	28.00	29.00	
		Length acquired	23.01	24.01	25.01	26.00*	27.00	28.00	29.00	
		Error	+0.01	+0.01	+0.01	0.00	0.00	0.00	0.00	
Sleeve armhole straight	A	Length required	-	25.00	26.00	27.00	28.00	29.00	-	0.30 cm
		Length acquired	-	25.43	26.21	27.00*	27.79	28.57	-	
		Error	-	+0.43	+0.21	0.00	-0.21	-0.43	-	
	D	Length required	24.00	25.00	26.00	27.00	28.00	29.00	30.00	
		Length acquired	24.63	25.43	26.21	27.00*	27.79	28.57	29.37	
		Error	+0.63	+0.43	+0.21	0.00	-0.21	-0.43	-0.63	
Under sleeve	A	Length required	-	14.00	14.50	15.00	15.50	16.00	-	0.25 cm
		Length acquired	-	13.82	14.40	15.00*	15.62	16.25	-	
		Error	-	-0.18	-0.10	0.00	+0.12	+0.25	-	
	D	Length required	13.50	14.00	14.50	15.00	15.50	16.00	16.50	
		Length acquired	13.26	13.82	14.40	15.00*	15.62	16.25	16.89	
		Error	-0.24	-0.18	-0.10	0.00	+0.12	+0.25	+0.39	

Note: * = Base size, Black = Length required, Blue = Exactly same, Green = Within tolerance, Red = Over tolerance limit, Units: Measured in 'cm'.

Experts affirm that the base size should be graded no more than two sizes before another fit model is implemented and the closer the individual to the fit model standard, the fewer alterations are required. Taylor and Shoben (1990) [24] argues against the 2D system of grading and they state "fitting and balance faults will automatically occur to the graded garment range" and they also indicate that "the 2D system can be safely used for very-loose-fitting garments over a very limited size range (three sizes)".

For this experiment, two spec sheets having two different size numbers were selected (Table 5).

After comparing Table 2 with Table 6, it can be deduced that as the number of size increases, grading error increases as well. If the spec sheet contains 5 different sizes, the middle size should be selected [20]. But if the sizes are more than 7, then additional errors will be generated. Based on the previous studies this statement is well verified, Bye and DeLong (1994) [21] demonstrate that garment appearance and proportion are also affected when the pattern is graded more than two sizes from the base size while using standard grading practices. Moore et al. (2001) [23] recommend that no more than five sizes (two larger and two smaller) are to be graded together. The average size range would then require more than one base size. They gave examples of simplified systems that include grading information for nine sizes (three smaller and five larger than the base size), which is a common practice in the apparel industry. In accordance with the aforementioned studies, some CAD personnel in the industry generally perform the following things for minimizing grading errors instead of rectifying them. Even if number of sizes exceed 7 sizes or more, the total sizes are divided into two parts (e.g. a spec containing 10 different sizes). They thus separate them into two groups of 5 sizes each and then draw two patterns as the base size and finally grade them. However, if the size exceeds 15 sizes or more, the total sizes are divided into three groups, of which three base sizes are selected. Afterwards from the selected base size, three patterns are drawn and are then graded. It should also be noted that if it is possible to eliminate all the diagonal measurements from the spec sheet then the number of sizes in a size range does not influence the grading. Few companies within the industry fit more than one sample size, which is a common practice in the industry if garment sizes are more than five, like size 06 to size 18 with an increment of 2.

2.2.5 Combination of measurement points

Some lines can be drawn using different measurement combinations. For example, the shoulder line can be drawn using any two of the three

Table 7: Shoulder length comparison of different POMs combination

Combination of POMs	POMs direction	Reference spec.	Size→	S	M	L	XL	XXL	Tol (±)
If SD & S are given	Vertical & Diagonal	A	Required	15.00	16.00	17.00	18.00	19.00	0.15 cm
			Acquired	15.10	16.05	17.00*	17.96	18.92	
			Error	+0.10	+0.05	0.00	-0.04	-0.08	
If AS & S are given	Horizontal & Diagonal	B	Required	15.00	16.00	17.00	18.00	19.00	
			Acquired	15.07	16.03	17.00*	17.97	18.95	
			Error	+0.07	+0.03	0.00	-0.03	-0.05	
If AS & SD are given	Horizontal & Vertical	C	Required	15.34	16.29	17.24	18.20	19.16	
			Acquired	15.34	16.29	17.24	18.20	19.16	
			Error	0.00	0.00	0.00	0.00	0.00	
N.B. The value of column B is not given for Spec C because, according to that spec sheet, we need AS and SD to be correct. They thus must be compared them to get the shoulder.									
If AS & SD are given	Horizontal	C	Required AS	45.00	48.00	51.00	54.00	57.00	0.25 cm
			Acquired AS	45.00	48.00	51.00	54.00	57.00	
			Error	0.00	0.00	0.00	0.00	0.00	
	Vertical	C	Required SD	5.00	5.00	5.00	5.00	5.00	-
			Acquired SD	5.00	5.00	5.00	5.00	5.00	
			Error	0.00	0.00	0.00	0.00	0.00	

*Note: * = Base size, Black = Length required, Blue = Exactly same, Green = Within tolerance, Red = Over tolerance limit, Units: Measured in 'cm'.*

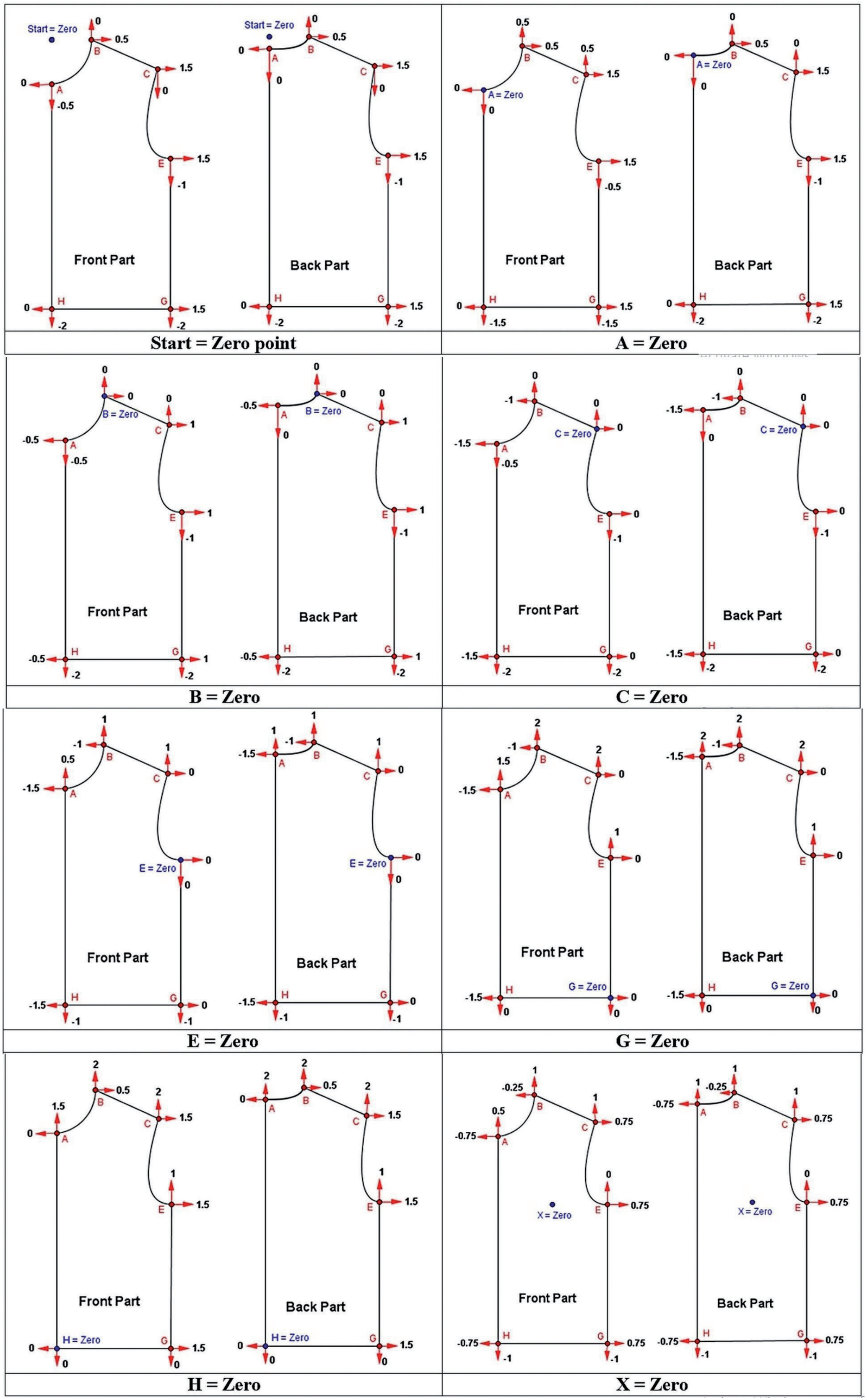


Figure 3: Grading increment of T-shirt Spec A (body part) by changing zero point

measurements, "Shoulder Length, Shoulder Drop and Across Shoulder Width".

It must be noted that some cardinal points of the pattern (e.g. shoulder point) can be created by using different measurement combinations. For instance, a shoulder point can be created if spec sheet contains horizontal-inclined (e.g. AS and S) or vertical-inclined (e.g. SD and S) or the horizontal-vertical (e.g. AS and SD) measurement combination. However, among the three options, the horizontal-vertical combination is preferable during pattern making as the measurement changes during grading are plotted in the Cartesian coordinates. For this experiment, three spec sheets A, B and C were chosen and were graded from base size L (middle size).

Table 7 clearly shows that shoulder point grading increment can be calculated without any error if horizontal and vertical POM combination is used, which can be plotted in X and Y direction respectively. The inclined graded measurement errors would not generally exceed the tolerance limit when any cardinal point of a pattern (e.g. shoulder point) is created from a horizontal-inclined (e.g. AS and S) or vertical-inclined (e.g. SD and S) measurement combination. However, better accuracy is found in the case of a horizontal-vertical combination.

Horizontal and vertical POMs should be used instead of diagonal or inclined POMs to get the desired shape of the pattern. During spec sheet creation, spec sheet creators should thus use the horizontal and vertical measurements instead of inclined measurements wherever it is possible.

2.2.6 Selection of zero points

The selection of a zero point is required to calculate accurate grading increment value within a minimum amount of time.

At first, a zero point has to be selected to apply grade rules or grading increment values. Then the values are calculated for a different grade or cardinal points. Each pattern grading starts by identifying the grainline, the zero point of reference, and the points where increases (or decreases for smaller sizes) are to be applied. It is necessary for any grading method to establish a point of reference for each pattern piece known as the zero point [25]. Moore et al. (2001) [23] used the centre front (and back) at the waist as the point of reference throughout their book. Vong, A. L. (2011) [4] states that "the location of the zero point on the pattern may change the grade of the pattern; additional study of whether the drape of the garment changes when the zero point is moved is needed". To check the impact of zero-point selection in grading, an experiment was conducted from spec sheet B by changing the zero point as mentioned in Table 6, as well as in Figure 3.

Based on the experiment it is evident that the graded patterns consistently have the same measurements. It can therefore be concluded that the change in zero-point location does not impact the fitting unless the pattern is wrongly drafted. Consequently, the procedure was applied on the sleeve and the result remained the same. The presence of diagonal measurement produced some miscalculations, however, not due to the zero-point selection. If all the diagonal measurements are avoided, like for example in "spec C", the errors can be avoided as well.

Any cardinal point can be selected as zero point. However, the calculation becomes much easier if the starting point is selected as zero-point.

2.2.7 Angle of measurement

Criterion 1 of the book Sizing in Clothing written by Ashdown [25] states that "the measurement must be either horizontal or vertical". But even if the measurements are neither horizontal nor vertical, Pythagoras' law can be used for calculating grading increment properly. The angle is not a mandatory factor.

In the same book it is also stated that "the measurement must be either horizontal or vertical -shifting and edge-changes grading techniques use grading information that is either horizontal or vertical; angled measurements could be used for proportional grading or could be divided into horizontal and vertical components, but only if the angle is known." However, even if the angle is not given it can be calculated from the horizontal and the vertical component of measurement. Knowing the angle is not mandatory; an example is shown in Figure 4.

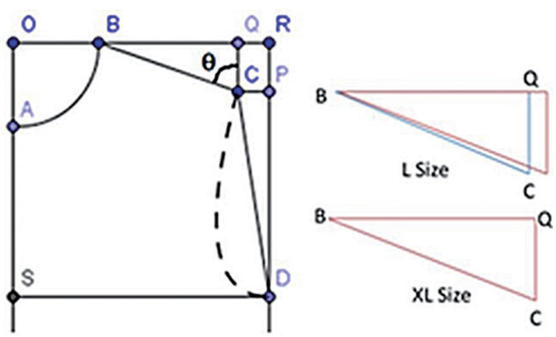


Figure 4: Body pattern of T-shirt (Spec A)

Angle can be measured by using the following formula:

$$\cos\theta = \frac{Shoulder\ drop}{Shoulder\ length} \tag{1}$$

$$\therefore \theta = cos^{-1}\frac{Shoulder\ drop}{Shoulder\ length} \tag{2}$$

After calculation the following data were found, Table 8.

In this way, it is not only possible to calculate the angle but also to reduce the grading errors. It must be noted that grading should be done manually or by using CAD software, which has an actual angle grading increment (e.g. Boke CAD) rather than employing an alternative reference line used by other software, such as Optitex, TUKA CAD, etc., which is elaborated more in section 2.2.9.

If diagonal measurements, such as shoulder length or armhole straight are given, then grading anomalies can be found. So, if diagonal measurements are given along with other horizontal or vertical components, then it is possible to calculate the angle and grade them to acquire more accurate graded measurements.

2.2.8 Alternative reference line

Some software uses an 'alternative reference line' for grading diagonal lines, but if the angle is not constant, they cannot grade the pattern accurately.

Generally, the reference line for grading is parallel to the grainline but sometimes an alternative reference line not parallel to the grainline is used. Taylor and Shoben (1984), Cooklin (1990), and Mullet et al., (2009) [6, 18, 26] use alternative reference lines for different garments when simple x and y orientation can distort the pattern shape. Generally, the alternative reference line is used for the shoulder/armscye point when the dart is rotated from the shoulder position [24, 27]. Mullet et al. (2009) [6] recommend alternative grade reference lines when "a style line on the pattern piece forms an acute angle to the grade reference line (x-axis) or when grading a curve that would be distorted by using the original axis".

From the above discussion, it can be deduced that the alternative reference line is only used for diagonal line grading. It is only applicable in case of most of the CAD software when the shoulders have the same angle, e.g. 17 degrees for all sizes. But if the shoulder angle varies from 17 degrees for L size to 18 degrees for XL size then most of the CAD cannot do that by

Table 8: Angle of shoulder slope of T-shirt body pattern (Spec A)

POMs	Remarks	Size					Unit
		S	M	L	XL	XXL	
Shoulder length?	Given in Spec A	15.00	16.00	17.00	18.00	19.00	cm
Shoulder drop		5.00	5.00	5.00	5.00	5.00	
Angle of BCQ (Figure 4)	Calculated values	70.53	71.79	72.90	73.87	74.74	Degree
Angle increment		-1.26	-1.11	Base	-0.97	-0.87	

Note: It is possible to calculate the angle of QBC also. But instead of QBC, BCQ is calculated because of angle grading by Boke CAD uses this angle, which is described in "2.2.9 Angle grading variation section"

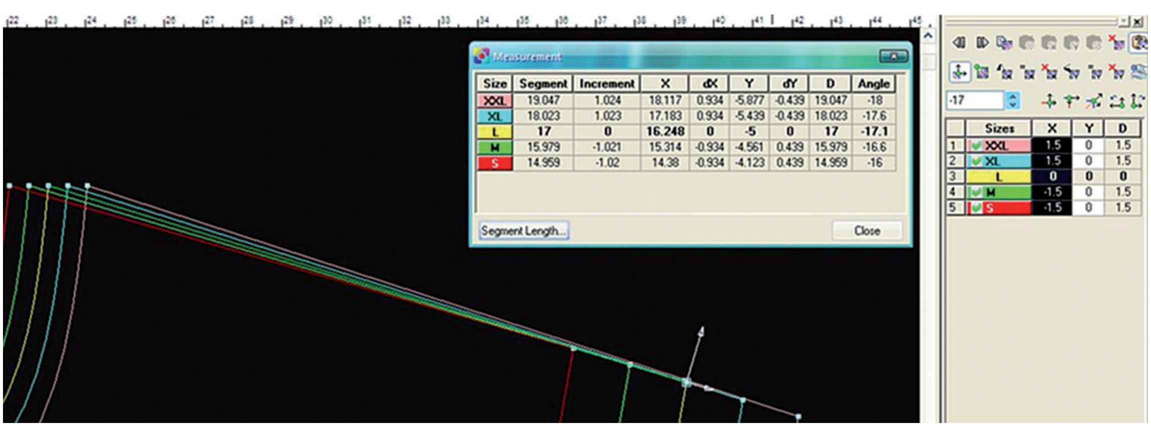


Figure 5: Shoulder grading of T-shirt Spec A by alternative reference line in TUKA CAD

Table 9: Comparison of measurement between XY grading and alternative reference line grading of Tshirt Spec A (TUKA CAD)

Points of measures (POMs)	Measurement comparison	Size					Tol (±)
		S	M	L	XL	XXL	
Shoulder length	Error with XY increment	+0.07	+0.03	0.00	-0.03	-0.05	0.20 cm
	Length with XY increment	15.07	16.03	17.00	17.97	18.95	
	Length required	15.00	16.00	17.00*	18.00	19.00	
	Length with alternative reference line	14.96	15.98	17.00	18.02	19.05	
	Error with alternative reference line	-0.04	-0.02	0.00	+0.02	+0.05	
Shoulder drop	Error with XY increment	0.00	0.00	0.00	0.00	0.00	0.00 cm
	Length with XY increment	5.00	5.00	5.00	5.00	5.00	
	Length required	5.00	5.00	5.00*	5.00	5.00	
	Length with alternative reference line	4.12	4.56	5.00	5.44	5.88	
	Error with alternative reference line	-0.88	-0.44	0.00	+0.44	+0.88	

*Note: * = Base size, Black = Length required, Blue = Exactly same, Green = Within tolerance, Red = Over tolerance limit, Units: Measured in 'cm'.*

alternative reference line, which is actually known as "Angle grading" as it will distort the across shoulder or shoulder drop measurement.

It is evident from the findings of Table 9 that alternative reference line grading cannot solve the grading problem.

If the angle is constant, then the usage of Optitex or TUKA CAD's alternative reference line grading is recommended.

2.2.9 Angle grading variation

Sometimes shoulder slope angle is not constant throughout all the sizes, so it results in grading error if alternative reference line grading is used.

Alternative reference line is actually known as 'angle grading' in apparel CAD software. Angle grading varies in different software such as TUKA CAD, Optitex etc. CAD system uses an alternative reference line in angle grading, whereas Boke CAD uses actual angle increment in angle grading. Examples are shown in Figure 6.

From the Table 10, it is clear that the actual angle grading can solve the grading problem.

If the angle remains inconstant then the use of Boke CAD's angle grading, instead of alternative reference line grading by Optitex, TUKA CAD software, etc is advised.

2.2.10 Selection of grade point or absence of certain measurements

Different shaping errors (e.g. armhole shape curve) occur due to the absence of some measurement points.

Grade point or cardinal points are those points that are present at the perimeter of the pattern and distribute the changes in body dimension [4]. Grade points are also known as cardinal points [6]. Solinger, (1988) [28] states that "when grading, the 'essence' of a garment should be maintained through all sizes". Doyle and Rodgers (2003) [17] state the importance of keeping the curves of the base pattern consistent: "If the grader changes the shape of the curve, the fit of the garment changes". Taylor and Shoben (2004) [18] state that while grading the armhole shape, "the angles at the cardinal point on the pattern must remain the same on all sizes". After grading, seam lines of the

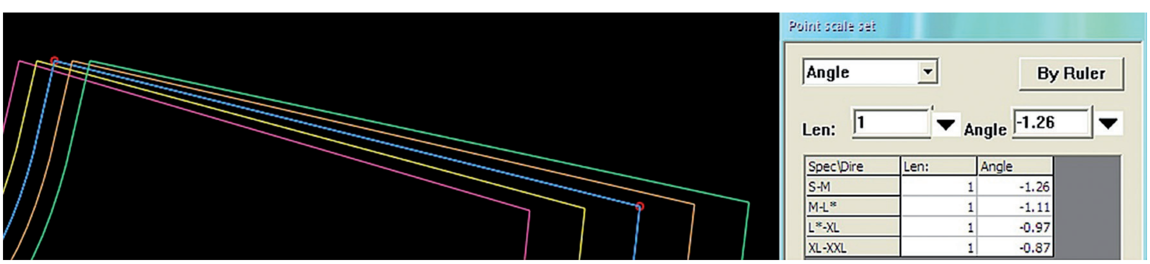


Figure 6: Shoulder grading of T-shirt spec A by actual angle grading in Boke CAD

Table 10: Comparison of measurement between XY grading and angle grading of T-shirt spec A by Boke CAD (shoulder length and shoulder drop)

Points of Measures (POMs)	Measurement comparison	Size					Unit
		S	M	L	XL	XXL	
Shoulder Length	Error with XY increment	+0.10	+0.05	0.00	-0.04	-0.08	cm
	Length with XY increment	15.10	16.05	17.00	19.96	18.92	
	Length Required	15.00	16.00	17.00*	18.00	19.00	
	Length with angle grading	15.00	16.00	17.00	18.00	19.00	
	Error with angle grading	0.00	0.00	0.00	0.00	0.00	
Shoulder drop	Error with XY increment	0.00	0.00	0.00	0.00	0.00	
	Length with XY increment	5.00	5.00	5.00	5.00	5.00	
	Length Required	5.00	5.00	5.00*	5.00	5.00	
	Length with actual angle	5.00	5.00	5.00	5.00	5.00	
	Error with actual angle	0.00	0.00	0.00	0.00	0.00	

*Note: * = Base size, Black = Length required, Blue = Exactly same, Green = Within tolerance, Red = Over tolerance limit, Units: Measured in 'cm'.*

graded pattern should be checked to ensure that they are of the same length during sewing.

Some spec sheets provide measurements for across chest and back. Occasionally, such measurements are absent in some spec sheets. In that case, pattern makers construct front and back armhole curve lines from shoulder point to underarm point. Sometimes the shape of armhole curves might be imperfect due to the absence of armhole curve depth, i.e. absence of across chest and across back measurements. And if these measurements are not given, the grading increment values for middle point of the curves (e.g. across chest and across back point) remain unknown. Different examples of armhole curve shapes are shown in Figure 7, indicated by red, green and blue colour.

If the across chest and across back measurements are provided in the spec sheet, the curves become more precise. When the curves are drawn from the shoulder point, across chest or across back and underarm point to avoid the fitting problem the curves do not require readjustment for adjacent sizes as then grading increment values can be calculated.

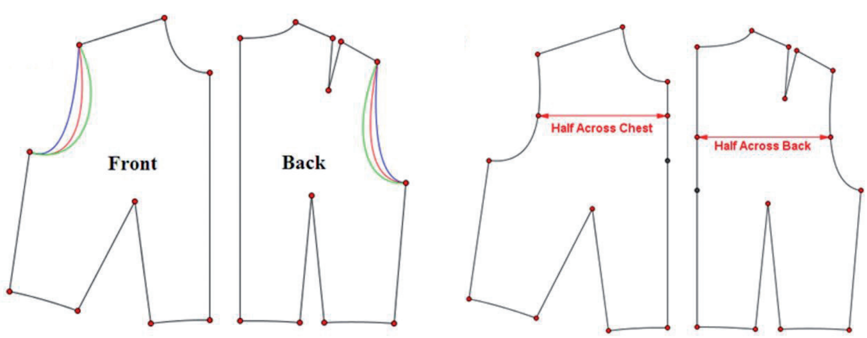
In short, across chest and across back measurements are to be used for drawing armhole shape curves accurately. Most of the time, pattern shape related problems occur due to the absence of curve depth. So, if AC and AB are given, then armhole shape curves can be drawn through three points: shoulder point, across chest/across back point and armpit point.

Across chest and across back measurements should be used for drawing armhole shape curves. For better armhole shape, the following things can be done:

- Manual drawing by French curve [29]
- Saving and selection of curve (e.g. Gemini CAD French curve tool)

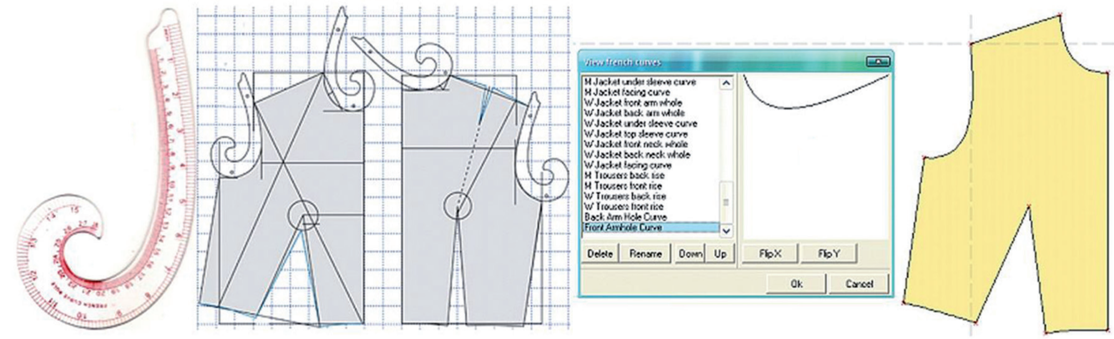
2.2.11 Absence of measurement location

If some measurements are absent in the spec sheet (e.g. across chest and across back position) or even



a) b)

Figure 7: a) Tentative armhole curve from shoulder point to armpit point without across chest and across back; b) accurate armhole curve from shoulder point to armpit point with across chest and across back measurements



a) b)

Figure 8: a) French curve and their uses for manual armhole curve drawing; b) saving and selection of curve by Gemini CAD French curve tool

in the standard measurement chart, the shape of the pattern changes and fitting problems occur.

Some spec sheets have across chest and back but do not have their vertical position from HPS. Sometimes, they are not properly clarified in standard measurement charts. Different pattern making books provide different guidelines on how to make the vertical position of across chest and back measurements. Different armhole curves were therefore drawn indicating different colours in Figure 9 according to the different procedures, which are mentioned below.

In the developed method, across chest position from armpit point (X–Y, in Figure 10) is one-third of armscye depth (W–X, in Figure 10) and across back position from armpit point (XX–YY, in Figure 10) is one-third of armscye depth (WW–XX, in Figure 10).

It can be concluded from Figure 9 and Figure 10 that green and red colour give more accurate shapes.

For better armhole curve shape, the across chest and across back position should be drawn by dividing the armscye depth into two-third of its original length from the neck point, if across chest and across back position are absent.

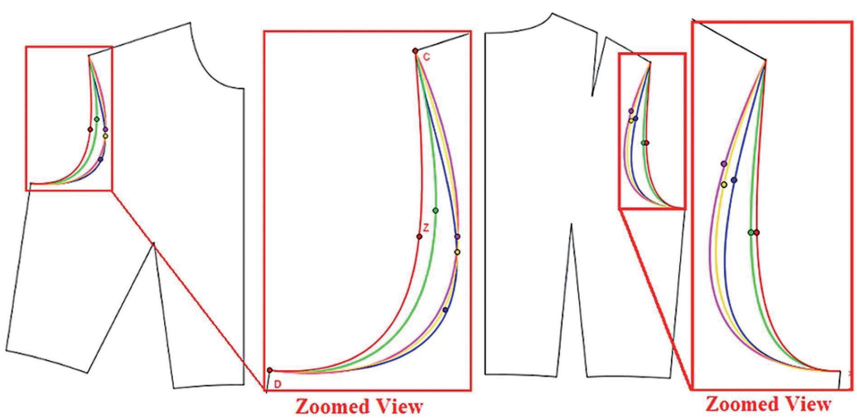


Figure 9: Front bodice and back bodice with five different armhole curve shapes constructed with different procedures

Table 11: Colour code of armhole curve, including developed method for across chest and back position

Colour code	Method
Red	developed method
Blue	Helen Joseph Armstrong (2010)[30]
Green	Winifred Aldrich (2008) [31]
Pink	Bina Abling and Kathleen Maggio (2008) [32]
Gold	http://fashionauntie.blogspot.com/2012/02/first-stages-of-pattern-drafting-for.html [33]

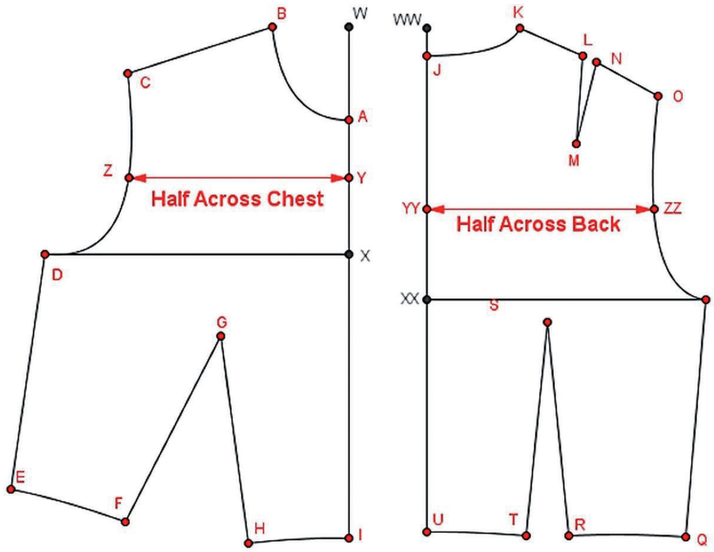


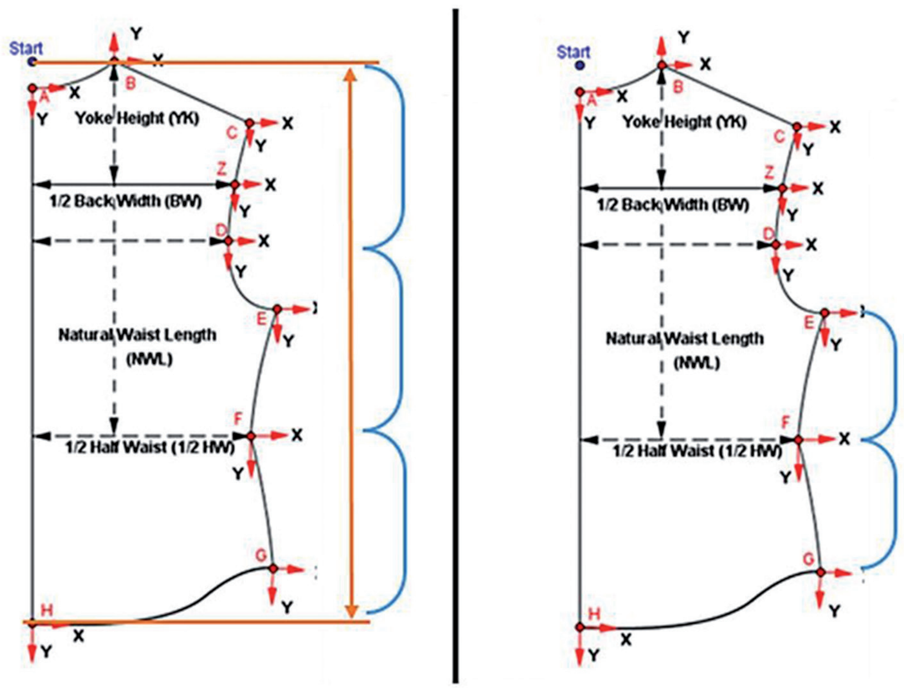
Figure 10: Front and back part of bodice block [developed method]

2.2.12 Lack of proper drafting procedure

Inadequate drafting procedure can sometimes lead to grading errors as the grading relates to the pattern making procedure.

Sometimes buyers gave us a soft copy of a pattern along with the spec sheet. Then the pattern maker graded the pattern. So, if the drafting procedure is unknown to the grader, grading errors are plausible.

On some other occasions, buyers gave us a soft copy of pattern along with the spec sheet but without any natural waist length (NWL) measurement (Figure 11). Different pattern makers use different techniques to meet the standard length of given measurements in the spec sheet, if it is absent in the spec sheet. For instance, some pattern makers use "2/3 of the total body length from high point of shoulder to ½ waist



A) B)

Figure 11: Different drafting procedure of NWL

position" for calculating NWL if it is not provided in the spec sheet. According to the 8 head theory, the NWL position is the second head position from the neckline, and hip position is the third head position (Figure 11A). Other pattern makers use half of the side seam measurements (Figure 11B). So, if any measurement or procedure is unknown to the grader it then becomes very difficult to grade the pattern with accurate measurement.

It can be concluded from Figure 11 that if the procedure is unknown to the grader it leads to grading errors as grading increment value depends on the pattern drafting procedure. When manufacturers only need to grade the pattern, the grader should be familiar with the procedure unless the grading increment values are provided in the Tech Pack.

2.2.13 Non-identifiable body landmarks or unusual measurement

Some measurements used in the spec sheet do not relate to the identifiable body landmarks. Furthermore, measurements are sometimes unknown to the majority of pattern makers.

Different pattern makers use different methods along with different measurements for the same design. But some measurements used in the body measurement chart are not related to the identifiable body landmarks. For example, a world-famous pattern maker Helen Joseph Armstrong (2010) [30] uses 'new strap measurement' (Figure 12), which is neither used by any pattern maker nor present in any body-measurement chart.

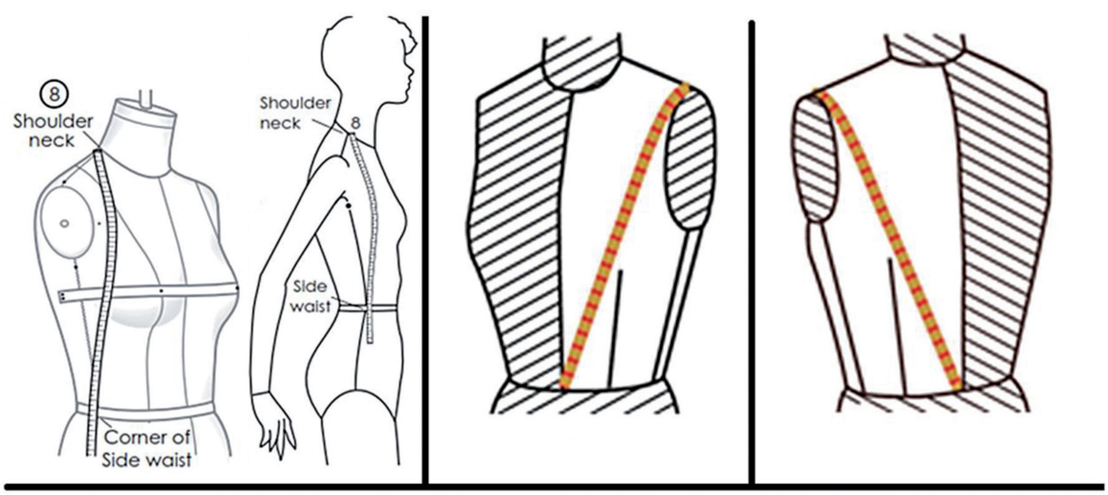
Though Helen Joseph Armstrong's (2010) [30] method gives the best fitting due to unconventional measurement, it would be difficult to grade the pattern. As seen in Figure 12, the measurement is neither perfectly diagonal nor a curve measurement, which can be measured through some definite points. In pattern making such measurements should be used that do not impact the grading and unusual measurements should therefore be avoided if they cause grading deficiencies.

2.2.14 Manual vs. computerised method of grading

Manual grading is a time-consuming and troublesome process whereas computerised grading is much more convenient and precise.

Often, the accuracy of the graded pattern pieces of clothing is affected by grader's skill [34]. The manual procedure of grading is exceptionally tedious and grading efficiency is affected by grader's experience [14]. Although the 2D CAD system provides time-saving solutions, they are not free from limitations. The grade rule creation or grading increment calculation is used by all types of 2D CAD system for apparel. But to complete the grading process, manual calculation and inputs are required for 2D CAD [14]. Computerised pattern grading is the most precise and expedient method but only when the accurate values are entered into the computer [6].

It is evident that manual grading is less efficient than the computerised method and usage of computerised grading is therefore recommended if possible.



A) B) C)

Figure 12: List of some non-identifiable body measurements. A – new strap, B – front shoulder slope, C – back shoulder slope

3 Results and discussion

After conducting all grading experiments, different problems are identified and finally, some recommendations are given for every problem. Different kinds of spec sheets were provided by different buyers with different POM variations. So, it is necessary to learn the proper grading calculation method and how the patterns are actually made from different measurements. Grade rule calculation has to be done in such a way that minimum measurement errors occur from graded pattern pieces and also, styles features left intact. The recommendations are given so that pattern graders can use them as a reference or guideline to avoid unnecessary grading problems.

3.1 General recommendations

i. **Presence of diagonal measurements.** The diagonal measurements should be avoided as much as possible in the spec sheet because they cause grading deficiency.

ii. **Maintaining accuracy and matching of curve lines.** Measurement checking and optimisation of the grading increment should be done until the required curve lengths are achieved.

iii. **Selection of base size.** If diagonal measurements are provided, then grading should be done from middle size to all sizes in order to reduce measurements errors.

iv. **Presence of higher number of sizes.** If the spec sheet contains 5 to 7 sizes, the middle size should be selected. If the number of sizes exceeds 7 or more, then the total number of sizes should be divided into two parts, and two base sizes should be selected. Afterwards, grading should be done by drawing two separate patterns. Even if the number of total sizes exceeds 15 or more, the total sizes should be divided into three individual parts. And then by selecting three base sizes, three individual patterns are to be drawn and later graded. It should also be noted that if it is possible to eliminate all the diagonal measurements from the spec sheet then the number of sizes in a size range does not influence the grading.

v. **Combination of measurements.** Horizontal and vertical POMs should be used instead of diagonal or inclined POMs to achieve the desired shape of pattern wherever possible. During the creation of spec sheets, spec sheet creators should use horizontal and vertical measurements instead of inclined measurements wherever possible.

vi. **Selection of zero points.** Any cardinal point can be selected as zero point but if the starting point is selected as zero-point, the calculation becomes easier. The starting point should therefore be chosen as zero point.

vii. **The angle of measurement.** If diagonal measurements, such as shoulder or armhole straight are given, then grading anomalies are found. If diagonal measurements are provided along with other horizontal or vertical components, then it is possible to calculate the angle and grade them to get more accurate graded measurements.

viii. **Alternative reference line.** If the angle is constant, then the usage of Optitex or TUKA CAD's alternative reference line grading is recommended.

ix. **Angle grading variation.** If the angle is not constant then the usage of Boke CAD's angle grading instead of alternative reference line grading by Optitex, TUKA CAD software etc. are advised.

x. **Selection of grade point or absence of certain measurements.** Across chest and across back measurements are to be used for drawing armhole shape curves. For better armhole shape, the following recommendations can be employed: A) Manual drawing by French curve, B) Saving and selection of curve (e.g. Gemini CAD French curve tool).

xi. **Absence of measurement location.** For better armhole curve shape, the across chest and across back position should be drawn by dividing the armscye depth into 2/3 from neck point if across chest and across back position are not given.

xii. **Lack of proper drafting procedure.** When manufacturers only need to grade the pattern, the procedure should be well-known to the grader unless the grading increment values are provided in the Tech Pack.

xiii. **Non-identifiable body landmarks or unusual measurement.** Unusual measurements should be avoided if they cause grading deficiencies.

xiv. **Manual vs. computerised method of grading.** It is evident that manual grading is less efficient than a computerised method, so it is recommended to use computerised grading if possible.

4 Conclusion

Pattern grading is the most popular method in ready-made garment industries for large scale manufacturing of different sizes, even though grading calculation can sometimes be complex. Grading is still popular because it is less time consuming and cost-efficient in making different sized patterns during production. However, defective grading affects other computerised downstream operations, such as computerised marker making and computerised cutting. It is important to note that although computer-aided applications contributed to minimising production costs and improving manufacturing efficiency, it cannot satisfy the customer's need for individualisation. Although grading calculation is very complex, patterns can be graded successfully without errors and distortion of style features, if the calculation is done properly. It will not only reduce the sample approval time, but will also help us to create clothing that fits better on the wearer's body.

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Sukhvir Singh
Mody University of Science and Technology, School of Design,
First Street, 512, ABB Building, Lakshmangarh, Rajasthan 332311 India

Development of a Collection of Garments Inspired by the Hawa Mahal Historical Monument

Razvoj kolekcije oblačil, navdihnjene z zgodovinskim spomenikom Hawa Mahal

Short scientific article/*Kratki znanstveni prispevek*
Received/*Prispelo* 5-2020 • Accepted/*Sprejeto* 6-2020

Corresponding author/*Korespondenčni avtor:*
Sukhvir Singh
E-mail: sukh7911@gmail.com
ORCID: 0000-0002-4010-5291

Abstract

Sources of inspiration play a vital role during the initial stages of the fashion design process by providing a specific direction to the entire fashion design process. Fashion designers interpret their imagination to improve the creative use of design inspirations during the development of clothing collections. Such exploration for design inspiration is crucial in the fashion design process for absorbing visual ideas and translating them into original creative clothing. The uniqueness of such creatively and systematically designed original clothing will also improve significantly. The current study focuses on the systematic development of a collection of casual women's wear inspired by the Hawa Mahal (The Palace of Winds) historical monument in Jaipur, Rajasthan. The fabric patterns were developed by extracting motifs from the Hawa Mahal architectural marvel using computer-aided designing solutions and digital printing with hand embroidery. In order to check the market potential of developed garments, a mini-survey was also conducted to analyse the extent of the appropriateness of garment silhouettes, fitting and drape, and overall aesthetic features among targeted consumers.
Keywords: fabric pattern design, historical motif, clothing collection

Izvleček

Viri navdiha igrajo ključno vlogo v začetnih fazah modnega oblikovanja, tako da določijo smer celotnemu procesu modnega oblikovanja. Modni oblikovalci interpretirajo svojo domišljijo z namenom, da bi izboljšali kreativno uporabo oblikovalskega navdiha za razvoj kolekcije oblačil. Takšno raziskovanje oblikovalskega navdiha je ključnega pomena pri modnem oblikovanju, in sicer za dojemanje vizualnih idej in njihovo prevajanje v izvirna kreativna oblačila. Tako se edinstvenost takšnih ustvarjalno in sistematično zasnovanih izvirnih oblačil tudi bistveno izboljša. Ta študija se osredinja na sistematičen razvoj kolekcije sproščenih ženskih oblačil, ki jih je navdihnil zgodovinski spomenik Hawa Mahal Palača vetrov iz Džaipurja v Radžastanu. Vzorci tkanin so bili razviti na podlagi motivov iz arhitekturnega čudesa Hawa Mahal z uporabo računalniško podprtih oblikovalskih rešitev in uporabo digitalnega tiska z ročnim vezenjem. Za preverjanje tržnega potenciala razvitih oblačil je bila izvedena manjša anketa med ciljnimi potrošniki, da bi ugotovili ustreznost silhuet oblačil, prileganja in drapiranja ter splošnih estetskih lastnosti.
Ključne besede: oblikovanje vzorcev tkanin, zgodovinski motiv, kolekcija oblačil

1 Introduction

The fashion design process is the systematic and sequential creative activity of incorporating research from different sources, analysing scrutinized inputs and utilising the information effectively and efficiently to achieve the desired outcome [1–4]. A fashion designer seeks inspiration from various natural sources, such as flora and fauna, and from architectural monuments and the virtual world [5–6]. One of the key characteristic quality features of a successful fashion designer is the ability to be a good absorber of visual ideas, creative thinker and skilled interpreter. In order to achieve the desired output, a fashion designer should be able to utilize the inputs from different sources in line with design principles and design empathy. Such practice is crucial to improving creativity, originality and uniqueness in a design [7–8]. In the process of apparel range development, the sources of design inspiration play a significant role by providing the right direction to the entire early design process [9]. Unlike other previously developed products, new product development also includes design taking into account functionality, aesthetics and expressiveness [10]. Thus, a uniquely designed product reveals many things about the visual perception of the designers.

Fashion designers anticipate trending styles, colours, silhouettes and materials based on the outcome of their research and observations from numerous sources. Architectural monuments, including historical monuments, can also serve as great sources of inspiration for fashion designers [11–13]. There exists a strong connection between fashion and architecture due to similarities in the design process and equal applications of basic design elements and principles. According to the famous designer Coco Chanel, "Fashion is architecture: it's a matter of proportion" [14]. Modern architecture or a historical monument can be a great source of garment silhouettes, derived motifs and patterns [15–16]. In the recent past, many renowned fashion designers also took inspiration from architectural monuments [17–19].

The Hawa Mahal, known as the Palace of Winds, is a major tourist attraction of the UNESCO world heritage city Jaipur, Rajasthan. It is also known as the pride of the pink city Jaipur due to its unique architectural resemblance to the honeycomb structure of a pyramid shape. The Hawa Mahal was specially designed for queens who gazed outside through the 953 perforated windows (Jharokhas) that keep the Hawa Mahal cool. The Hawa Mahal was constructed in 1799 by Maharaja Sawai Pratap Singh from red and pink sandstone [20]. Due to the characteristic features of the Hawa Mahal, it is not just an architectural marvel of Jaipur, but also a great source of inspiration for designers.

This study focuses on the development of a collection of casual wear for women inspired by the famous Hawa Mahal historical monument situated in state capital Jaipur of Rajasthan. The focus of the current study was more on deriving and developing motifs for an apparel range inspired by the Hawa Mahal. The patterns of the garment collection was developed after deriving, scrutinizing and analysing the development of the motif using computer-aided design. The process of motif development requires a great deal of effort, scrutiny and patience. Once the motifs were ready, it was comparatively easier to convert these developed motifs into desired patterns. The development of fabric appearance was carried out using digital printing and hand embroidery techniques. Consumer behaviour was also observed by conducting market research in order to analyse the market potential of products in terms of garment silhouettes, drape and fitting and the overall aesthetic features of developed garments.

2 Materials and methods

2.1 Material

Due to the exceptional comfort properties of cotton, 100% cotton fabric of 125 g/m^2 (GSM) was used for the final development of a collection comprising five garments. The cotton fabric was sourced from the local market of the city of Jaipur. The women's casual wear collection produced using breathable cotton fabrics also meets the requirements of targeted consumers of Jaipur, Rajasthan. That casual wear is also the preferred choice of consumers for summer wear for hot and humid Indian tropical conditions.

2.2 Methods

An eight-step new product development process was considered for the development of a range of women's casual summer wear. Those eight steps include idea generation, idea screening, concept development and testing, marketing strategy development, business analysis, product development, market testing and commercialisation [21–22]. Idea generation and idea screening help in filtering infeasible ideas through brainstorming. Developing a concept focuses on design and features, whereas developing a marketing strategy deals with identifying the target market, product positioning, pricing and distribution, and marketing communication. Business analysis is performed to verify the economic viability of the concept by projecting sales and profit. Moreover, a product is developed and initially tested on the market on a small scale before product commercialisation. Among all involved steps, a few steps, such as a part of business analysis and product commercialisation, were kept optional and skipped due to study feasibility limitations. In order to observe and analyse the taste of targeted consumers of the city of Jaipur, a mini-survey was conducted among young females aged 18–25 years. The control factors considered for this survey were garment silhouettes, garment drape and fit, and the overall aesthetic features of the garment. The frequency of respondents' responses in terms of acceptance was recorded individually for each garment. A total of 500 respondents from various background (students, corporate sector employees and academic professionals) shared their feedback in the mini-survey, which was conducted to observe and analyse the market potential of the developed garments during the initial stage. For each garment sample, 100 randomly selected respondents were asked to give a score out of 100 for control factors, such as garment silhouettes, fitting and drape, and the overall aesthetics of the garment. The mean value of these 100 readings was determined for individual garments and expressed in percentages, as shown in Table 1 in the results and discussion section.

Clothing comfort is crucial when selecting a garment silhouette for modern targeted consumers. Garment silhouettes with a wide-cut were incorporated to facilitate better movement and improved air permeability. The focus of this study was deriving and developing motifs using computer-aided design and then depicting scrutinized motifs on fabric using digital printing and hand embroidery techniques. Digital printing was selected for depicting developed motifs because of the higher accuracy of the print quality. Along with digital printing, hand embroidery was considered an effective tool for additional surface embellishment and is very popular among local consumers.

3 Results and discussion

3.1 Motif development

In this study, the motifs were derived and developed using computer-aided design software, including Adobe Illustrator and Optitex PDS from the source of inspiration, which was the Hawa Mahal historical monument. In the initial stage, photographs of

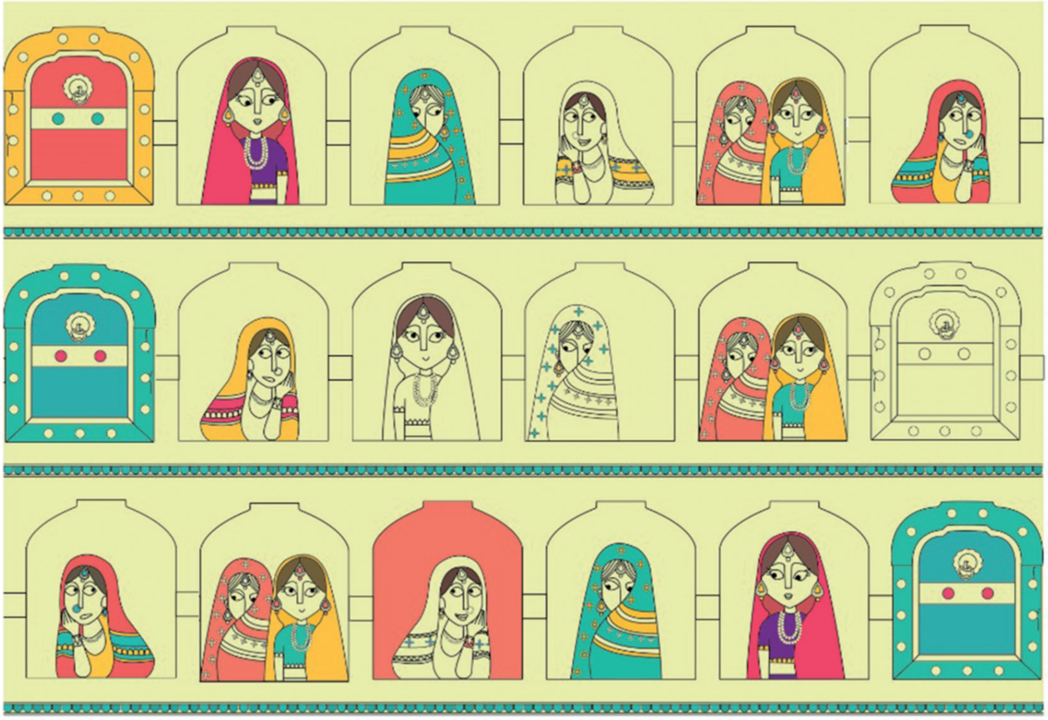

Figure 1: Royal women gazing through the iconic "Jharokha" window of the Hawa Mahal

some unique and inspiring elements and sequences were taken by visiting Hawa Mahal. A motif of royal women gazing through the uniquely designed "Jharokha" windows of the Hawa Mahal depicts the richness of the 18th century costumes of royal women from Jaipur, Rajasthan, as shown in the Figure 1.

The second scrutinized motif used for pattern development was a motif inspired by the uniquely designed iconic "Jharokha" windows of the Hawa Mahal, which serve as the smallest unit of repetition in the honeycomb structure of the front side of the Hawa Mahal. It consists of one main window in the front and two relatively smaller side windows, as shown in Figure 2. The motif developed for creating a pattern is shown in Figure 2, together with a pigeon. A pigeon is included here because, in front of the Hawa Mahal, hundreds of pigeons sit on the electric wires outside of this architectural marvel at all times. These birds sitting on the wires add beauty to the Hawa Mahal, as "the birds seem motionless as if in meditation," described Gulzar [23].

Among many other developed motifs, the third motif is a depiction of the front view of theHawa Mahal, which is a honeycomb structure made up of the repetition of rows and columns of the iconic "Jharokhas" windows of the Hawa Mahal,as shown in Figure 3.

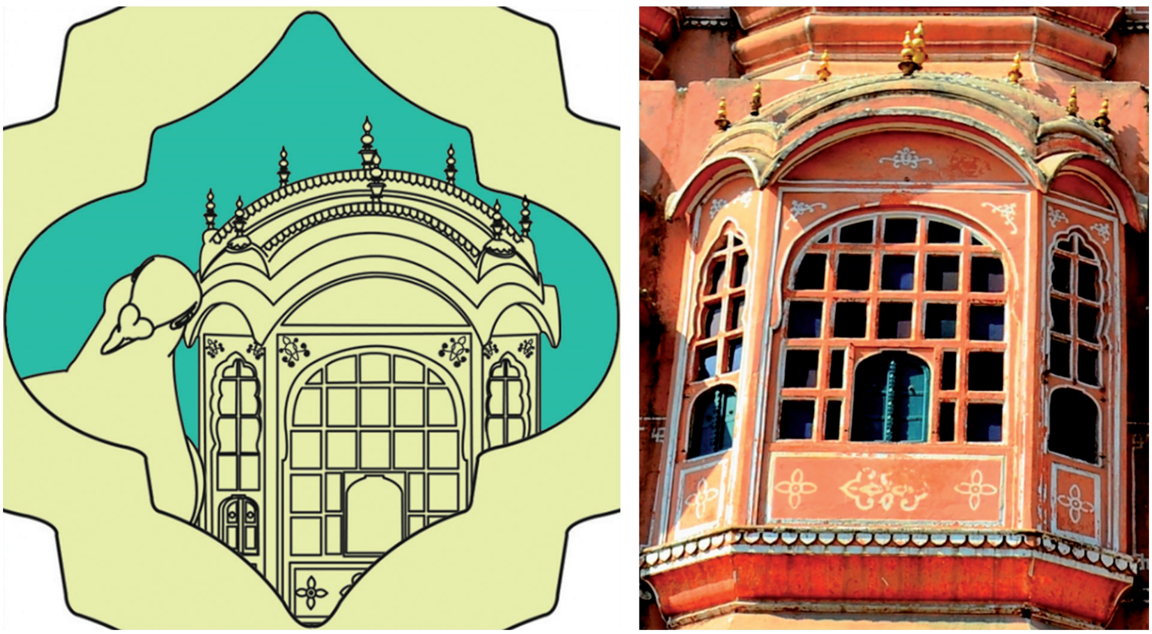

Figure 2: Motif developed (left) from the iconic "Jharokha" windows (right) of the Hawa Mahal

Figure 3: Honeycomb structure created (left) inspired by "Jharokhas" used in the Hawa Mahal (right)

3.2 Fabric pattern design

The developed and scrutinized motifs were then printed on good-quality 100% cotton fabric purchased from the local market. When selecting printing techniques, digital printing was selected over to other printing techniques due to the desired print accuracy and good overall print quality on the fabric. Apart from digital printing, hand embroidery using basic stitches, such as a simple running stitch, cross stitch, etc. was also adopted for further fabric surface embellishment. Hand embroidery was also incorporated due to the huge demand for such products among the targeted consumers of the Jaipur region. A piece of the sample depicting the conversion of the developed motif to printed and embroidered fabric surface is shown in Figures 4–7.

Figure 4: Motif developed (left) depicting royal women gazing through "Jharokha"

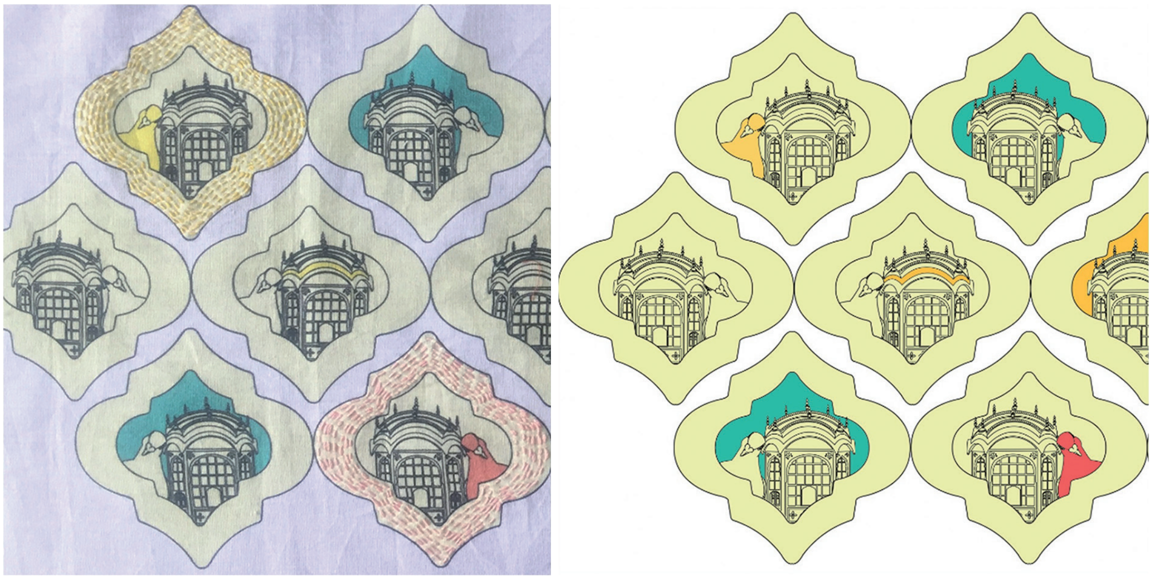

Figure 5: Pattern developed on fabric surface (left) using a developed motif (right)

Figure 6: Developed motif (left) and prepared fabric samples (right)

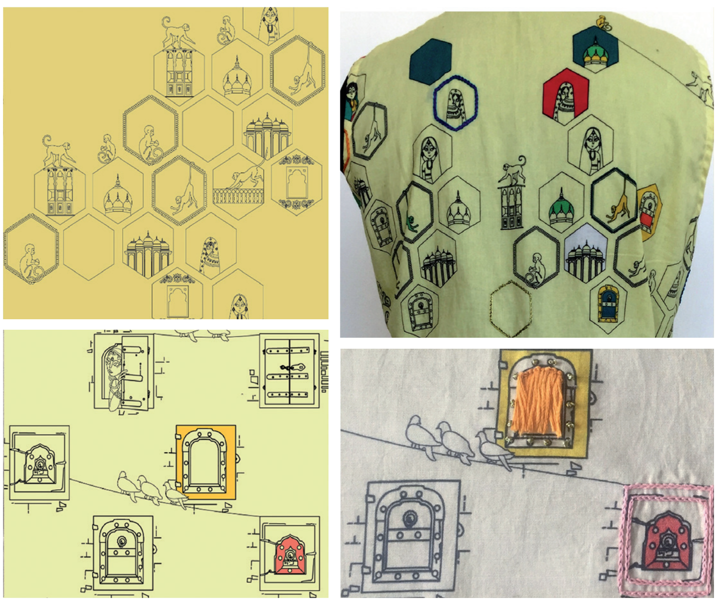

Figure 7: Pattern development using CAD (left) and fabric surface developed (right)

3.3 Garment collection planning and development

Garment collection planning was carried out meticulously and systematically through sufficient research and after incorporating suggestions from previous studies. A detailed study was conducted to select garment silhouettes, colour combinations, variations in products, fitting and drape, and the overall aesthetic features of the final garments. Initially, a garment collection was developed using basic computer-aided design solutions, such as Adobe Illustratorand Optitex PDS. Toile garment samples were prepared in order to determine the silhouette directions of the garments.

The final five garments of the women's summer wear collection were produced applying minimal variation from predefined styles and silhouettes, as shown in Figure 8. The garment collection was produced using 100% cotton fabric with a weight of 125 g/m^2, which is suitable for summer wear. The patterns developed using computer-aided designs were then printed using a Yuhan-Kimberly digital printer. The patterns of the printed fabrics were then cut and sewn using an industrial grade JUKI machine according to predefined sizes and silhouettes. Finally, hand embroidery was performed using different stitches on some selected motifs of different garments.

Figure 8: Garment collection developed using CAD (above) and developed garments (below)

It was observed that the use of computer-aided design helps in a more accurate visual interpretation of creative ideas by improving the originality and uniqueness of the designs. The use of digital printing for fabric surface development further improves design accuracy using a Yuhan-Kimberly digital printer. Hand embroidery was used to enhance the attractiveness and emphasise parts of the developed fabric surface. A few enlarged motifs samples prepared using different stitches of hand embroidery are shown in Figure 9.

Figure 9: Hand-embroidered samples prepared using different stitches

3.4 Market potential of developed garment collection

In the process of new product development, the market product potential of a product should also be verified. Thus, all five garment styles were tested for responses, such as the acceptance of silhouettes, garment drape and fitting, and overall aesthetics among targeted consumers of the Jaipur region. Based on the collective mean score of an individual garment, it was found that garment G2 (shown in Figure 8) scored highest, followed by garment G1 and garment G4, as shown in Table 1. The lowest collective mean score was observed in the case of garment G3 due to inappropriate silhouettes, drape and fitting, and poor overall aesthetic features, which was confirmed from visuals and from experimental results. The reasons behind the exceptionally good market potential of garment G2 were attractive garment silhouettes, better drape and enhanced overall aesthetics, contributing to improved consumer satisfaction relative to other garments. The results of the observed mean score for different control variables is shown in Table 1.

Table 1: Control variables and observed mean scores of garments

Contributing factors	Mean score				
	Garment 1 (G1)	Garment 2 (G2)	Garment 3 (G3)	Garment 4 (G4)	Garment 5 (G5)
Silhouettes	78.14	76.47	49.66	68.56	61.43
Garment drape andfitting	81.67	84.11	51.91	76.77	67.58
Overall aesthetics	73.45	83.34	54.73	71.34	64.45
Total mean score of garment	77.75	81.30	52.10	72.22	64.48

4 Conclusion

The new product development process was adopted for a range of women's summer wear inspired by the Hawa Mahal architectural marvel and historical monument. It was observed that computer-aided design is an effective and efficient way of interpreting the visual idea of the creative mind of the designers. Scrutinised motifs and subsequent patterns were extracted from the front view of the honeycomb structure of the Hawa Mahal using computer-aided design solutions. It was found that a digital printing technique was an effective approach to fabric pattern development. Basic hand embroidery was also incorporated to satisfy the requirements of target consumers, and was found to have a significant impact on the overall aesthetic features of the garment. The findings pertaining to the market potential of the developed garments reveal that garment G2 (81.30) achieved the highest collective mean score, followed by garment G1 (77.75) and G4 (72.22). These garments thus have a positive impact on used control variables among targeted consumers and reflect product success. The factors contributing to the promising market potential of these garments were attractive silhouettes, good garment drape and fit, and the appealing overall aesthetic features of the garments. Garment G3 (52.10) achieved the lowest collective score, as the merchandise failed to attract target consumers due to inappropriate garment silhouettes, fit and poor overall appearance. The current study was primarily conducted to understand the garment range development process using computer-aided design and the possible marketing feasibility of the developed range of garments. When conducting the survey, only a few imperative factors were considered. However, many other equally important factors, such as colour combination and psychological factors, may also be included in further research.

Acknowledgement

I would like to express my deep gratitude to Prof. (Dr.) Smriti Agarwal and Ms. Sanskriti Sharma of the School of Design, Mody University for their support at various stages of this study.

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Kamrun Nahar[1], Shurfun Nahar Arju[2], Jannatul Ferdush[1], Marzia Islam[1], Tarifun Akter[1]
[1] Northern University Bangladesh, Department of Textile Engineering,
Kawlar Jamea Masjid Road 111/2, Dhaskhin Khan, Khilkhet, Dhaka 1229, Bangladesh
[2] Bangladesh University of Textiles, Department of Wet Process Engineering,
Shaheed Tajuddin Ahmed Avenue 92, Tejgaon Industrial Area, Dhaka 1208, Bangladesh

Colorimetric Analysis and Fastness Properties of Jute Fabric Dyed with Eucalyptus Leaves

Kolorimetrična analiza in obstojnost jutne tkanine, barvane z listi evkaliptusa

Original scientific article/*Izvirni znanstveni članek*
Received/*Prispelo* 3-2020 • Accepted/*Sprejeto* 6-2020

Corresponding author/*Korespondenčna avtorica:*
Kamrun Nahar, senior lecturer
E-mail: kamrun.butex@gamil.com
Mobile: 8801731094445

Abstract

Natural dyestuff has reverted its position in the colouration of textile substrates due to rising concerns of consumers and buyers, particularly about environmental impacts and health issues. Eucalyptus leaves were selected in this study as a source of natural dye along with some of the most generally used mordants to observe the impact of dyeing on jute fabric while trying to keep the dyeing parameters at a minimum level. Dyes were extracted from eucalyptus leaves by boiling in water. Then, the fabric was pre-mordanted using different synthetic mordanting agents, such as alum, potassium dichromate, copper sulphate and ferrous sulphate, which are generally used to substantively enhance the dyestuff on textile fabrics and to improve the fastness properties. Synthetic mordant was used here instead of natural mordant due to the better dyeing compatibility of jute fabric with eucalyptus leaves, since natural mordant has little effect on jute fabric during the process of dyeing. Another aim of this research is to curb the time and energy consumption of the jute dyeing process and so the dyeing is carried out at 75 °C for about 30 minutes. Various types of evaluations were conducted through visual assessment, checking the colour-coordinate values and colour strength values. While colour fastness properties were evaluated by different fastness testing, such as colour fastness to water, washing, rubbing and perspiration. This dyeing process yields a colour range from yellowish to brown with the variation of mordants applied on the fabric. In addition to that, colour co-ordinate and colour strength values ensure better results of dyed fabrics pretreated with ferrous sulphate. Jute fabric dyed with only extracted eucalyptus solution provided satisfactory results in all colour fastness tests, while fabric treated with different mordants showed variations in fastness ratings, and fabric treated with ferrous sulphate and copper sulphate had slightly better fastness ratings.
Keywords: Colour-coordinate, colour fastness, eucalyptus leaves, jute fabric, mordant

Izvleček

Odnos do naravnih barvil za barvanje tekstilij se je spremenil ob skrbi potrošnikov in kupcev za okolje in zdravje. V tej študiji so bili izbrani listi evkaliptusa kot vir naravnega barvila skupaj z nekaterimi najpogosteje uporabljenimi čimžami, da bi ugotovili vpliv barvanja na jutno tkanino ob ohranitvi parametrov barvanja na minimalni ravni. Barvila so bila ekstrahirana iz listov evkaliptusa pri vrenju v vodi. Nato je bila tkanina najprej čimžana v prisotnosti različnih sintetičnih čimž, kot so galun, kalijev dikromat, bakrov sulfat in železov sulfat, ki se po navadi uporabljajo za izboljšanje substantiv-

nosti in obstojnosti barvila na tekstiliji. Namesto naravne čimže so bile zaradi boljše združljivosti barvanja jutne tkanine z listi evkaliptusa uporabljene sintetične čimže, ker naravne čimže med barvanjem v manjši meri vplivajo na jutno tkanino. Drugi cilj te raziskave je bil omejiti čas in porabo energije pri barvanju jute, tako da je barvanje potekalo približno 30 minut pri 75 °C. Opravljeni so bili različni načini ocenjevanja in sicer vizualno, preverjanje vrednosti barvnih koordinat in barvne jakosti. Barvna obstojnost je bila ocenjena z različnimi testiranji obstojnosti, kot je barvna obstojnost proti vodi, pranju, drgnjenju in znojenju. Ta postopek barvanja daje barvni razpon od rumenkaste do rjave barve glede na variiranje čimž, nanesenih na tkanino. Poleg tega barvne koordinate in jakost barve zagotavljajo boljše rezultate obarvanja tkanine kot pri predhodno obdelanih z železovim sulfatom. Jutna tkanina, barvana samo z raztopino evkaliptusovega ekstrakta, daje zadovoljive rezultate barvne obstojnosti za vse barvne tone, medtem ko tkanine, obdelane z različnimi čimžami, kažejo razlike v ocenah obstojnosti in nekoliko boljšo oceno le za tkanine, obdelane z železovim sulfatom in bakrovim sulfatom.
Ključne besede: barvna koordinata, barvna obstojnost, listi evkaliptusa, jutna tkanina, čimža

1 Introduction

From ancient times onwards, colour from natural sources has been used enormously in various areas on a daily basis; for food, hair, medicine, furniture and even fabrics. Colour from different parts of plants or insects, in particularly bark, roots, leaves, stems, flowers and fruits [1], has been used extravagantly to dye natural fibres (i.e. wool, silk, cotton and jute). But to cope with the ever increasing demands for clothing, people have decreased the application of natural dye and switched to synthetic dyestuff as it is available and easy to apply, it exhibits moderate to good colour fastness, is economical. Environmental awareness raised questions on the use of huge amounts of salts and alkalis, which has detrimental effects on human life, and in return the usage of natural dyes as well as environment-friendly fabrics was revived [2–4]. Since such dyestuff is non-toxic, biodegradable and some types of dye also have special antimicrobial, UV protective and anti-flammable properties, it will be the buyers' and consumers' first requirement in the near future. Natural dyes, however, have low substantivity for textile substrates, and for this reason various mordanting agents are used before, during and after the dyeing process, what is known as pre-mordanting/simultaneously mordanting or post-mordanting process. Alum, potassium dichromate, copper sulphate, ferrous sulphate, vinegar, tin, etc. were used as mordant to intensify the colouring properties and colour fastness [5–9]. Natural mordants, such as aloe vera, mango bark, oak bark, chestnut wood, etc. are environmentally friendly and act as an effective mordanting agent for protein fabrics (e.g. silk and wool), but not for the jute fabric [10]. On the other hand, compatibility of mordanting agent with natural dyes depends on the chromophores in the dyestuff and the fabric, which the dye has to be applied on. Considering the aforementioned disadvantage of natural mordants, synthetic mordants were applied here to establish, which synthetic mordant is best suited for the dyeing of jute fabric with eucalyptus leaves.

Eucalyptus leaves and bark are a substantial source of natural dyestuff that provides pale yellow to brownish colour [11]. About 10 to 12% of natural tannin and polyphenol in eucalyptus is responsible for the colouring of materials [12]. Quercetin is a major colouring component of eucalyptus bark and also an antioxidant, which is the reason for its utilisation in food colouring [13]. It is also used for colouration purposes of cotton fabrics [11, 14, 15].

Eucalyptus leaves contain up to 11% of tannin, gallic acid and ellagic acid – a pivotal part of phenolic acids and flavonoids, which enable the dyeing of natural fabrics, including wool and silk [16]. These two components are very useful in the dyeing process as they fix up the colour to the fabric.

On the other hand, jute is a nearly 100% biodegradable fibre and is used for various purposes in textile sectors, including technical textiles. However, natural colouration of jute substrate is scarce and it is therefore mostly dyed with basic dyes.

A study conducted by Rattanaphol Mongkholrattanasit1, Jiri Krystufek, Jakub Wiener and Rattanaphol Mongkholrattanasit showed what happens when natural dye was extracted from eucalyptus leaves and applied to wool fabric. They extended their research on the impact of natural dye extracted from eucalyptus leaves on silk and wool fabrics using two padding techniques under different conditions, i.e. the pad-batch and pad-dry techniques [17]. In another study, Nattadon Rungruangkitkrai1, Rattanaphol Mongkholrattanasit, Wirat Wongphakdee and Jarmila Studnickova examined a dye extracted from eucalyptus leaves and its application to wool fabric using pad-batch and pad-dry techniques under various conditions. The fastness properties of dyed fabrics ranged from good to excellent, while light fastness fair to good. The fabric had an excellent value of ultraviolet protection factor (UPF). In addition, a darker colour was a result of $FeSO_4$, which provided better protection due to its higher UV absorption [18, 19].

It is known that dyes from eucalyptus leaves are mostly applied on protein or cotton fabrics, but its application on jute fabrics is very limited. In this study, a eucalyptus leaves extract is used to dye the jute fabric at an optimum temperature and time. Besides, it assesses which mordanting agent is more compatible for the dyeing of jute fabric with extracted eucalyptus leaves in respect of colour coordinates and colour fastness.

2 Materials and methods

2.1 Materials

Substrate

A plain woven grey jute fabric with mass per unit area 249 gm/m^2 was used for dyeing. The fabric specifications were warp density 1.225 ends per meter, weft density 0.81 picks per meter and thickness 1.02 mm.

Natural dyes

Dye solutions were extracted from 20 g of eucalyptus leaves (i.e. Eucalyptus camaldulensis) that were collected in the Gazipur District. The leaves for extraction were gathered in November because during that time juvenile and adult leaves provide the most intense colour.

Firstly, green eucalyptus leaves were chopped into small pieces and soaked in soft water (20 g of green leaves in 2000 ml of water) and thereafter boiled for one hour. Then, all the colouring matter was mixed with water with the help of heat and the dye solution was reduced to approximately 1000 ml. The maximum absorbency of this extracted dyestuff was obtained in the wavelength of 420 nm.

Mordant

Four types of mordant: alum, ferrous sulphate ($FeSO_4$), potassium dichromate ($K_2Cr_2O_7$) and copper sulphate ($CuSO_4$) were used. All the mordants were 100% anhydrous, produced in the Northern University Textile lab, which was purchased from Mithila Chemicals Ltd.

2.2 Sample preparation

The preparation of jute fabric for dyeing with eucalyptus leaves includes a pre-treatment process and a pre-mordanting process so that it can absorb natural dyestuff easily. As a result, four mordanting agents were used to pre-mordant the bleached jute fabric (Table 1).

Bleaching of grey jute fabric

Bleaching of the raw jute fabric was carried out in a closed vessel for one hour at 50–52 °C keeping the material at a liquor ratio 1:20 with hydrogen peroxide, trisodium phosphate (5 g/l), sodium hydroxide (1 g/l), sodium silicate (10 g/l) and non-ionic detergent (5 g/l). The pH of the bath was 11. After the fabric was washed thoroughly in cold water, it was neutralised with acetic acid (2 ml/l), washed in water again and then air dried.

Mordanting of bleached jute fabric

Bleached jute fabrics were pre-mordanted separately with alum, $FeSO_4$, $CuSO_4$, $K_2Cr_2O_7$ at a similar concentration, i.e. 10% per weight of the fabric, at room temperature for about 24 hours, keeping the material at a liquor ratio 1:10. Then they were dyed without any washing.

Dyeing of mordanted jute fabric with natural dye

Jute fabrics that were pre-mordanted or not were dyed with the extracted dye solution from eucalyptus leaves at 75 °C for 30 minutes following the M:L = 1:20, which means that each of the 10 g jute fabric was dyed with 200 ml extracted dye solution at the above-mentioned dyeing parameters.

Table 1: Designation of the dyed sample

Sample designation	Sample description
S1	Bleached fabric without dyeing
S2	Fabric dyed without mordant
S3	Dyed fabric mordanted with alum
S4	Dyed fabric mordanted with potassium dichromate
S5	Dyed fabric mordanted with copper sulphate
S6	Dyed fabric mordanted with ferrous sulphate

2.3 Testing processes after dyeing

Measurement of colour coordinate

Using Datacolor® 850 Spectrophotometer the colour coordinate value of all dyed samples was measured by the CIE $L^*a^*b^*$ or the CIELCH method. CIE $L^*a^*b^*$ and CIELCH mean the following: *L* stands for lightness/darkness value, a^* is red/green axis where $+a$ represents redder and $-a$ represents greener, b^* is yellow/blue axis where $+b$ represents yellower and $-b$ bluer, *C* stands for chroma, *+ve* represents brighter and *-ve* represents duller, and *H* stands for hue.

Measurement of colour strength

The *K/S* value was assessed using the spectrophotometer to observe the colour strength of different reactive dyes, which works on the Kubelka-Munk equation 1:

$$\frac{K}{S} = \frac{(1-R)^2}{2\,R} \tag{1}$$

where, *R* is the reflectance of dyed fibre.

Evaluation of colour fastness to wash

The ISO 105 C06 B2S method was applied to measure wash colour fastness properties of the dyed sample. In this method, a dyed fabric (10 cm × 4 cm) is attached to a TV multi fibre fabric and an undyed fabric like a sandwich and the sample was treated with an ECE reference detergent, sodium perborate tetra hydrate, acetic acid at 40 °C for 30 minutes in a washing machine where M:L was 1:50. Then, colour fastness to wash was assessed in respect to colour change (ISO 105 A02) and colour staining (ISO 105 A03) by matching with standard grey scales.

Evaluation of colour fastness to water (ISO 105 E01)

This test method evaluates the effect of water on fastness properties of a dyed fabric. First, each sample was cut to a size of 10 cm × 4 cm along the length or width. Then, the sample was paired with a TV multifibre fabric and soaked into water for a half an hour. All wet samples were then placed in a perspirometer in an oven to simulate exposure for three hours. Lastly, the colour change of the sample and the staining of the multifibre strip were evaluated.

Assessment of wet and dry rubbing colour fastness (ISO 105-X12)

Dyed samples of 14 cm × 5 cm were mounted on a crock meter and the finger of the crock meter covered with a 5 cm × 5 cm crocking cloth at the pressure of 9 ± 2 N. The samples were rubbed with the finger at 10 turns within 10 seconds. But for the wet rubbing test this process is followed after soaking the crocking cloth in water at a 100% pickup.

Determination of perspiration fastness (ISO 105 E04)

Colour fastness to perspiration of all dyed samples was measured in media like acid and alkali following the ISO 105 E04 testing method. Like the samples (10 cm × 4 cm) for the wash and water fastness, a multifibre fabric and undyed fabric were further soaked in an alkali and acid solution. Alkali and acid solutions were prepared by using 0.5 g/l l-histidine monohydrochloride monohydrate, 5 g/l sodium chloride, disodium hydrogen orthophosphate dehydrate/sodium dihydrogen orthophosphate dehydrate and definite pH for acid and alkali. Testing samples had been dipped in this solution for about 30 minutes, then put in perspirometer at 37 °C for 4 hours in the oven. Then the samples were assessed.

3 Results and discussion

3.1 Visual appearance

It was observed from the pictorial view of all dyed samples (Figure 1) that jute fabric, which was dyed with only extracted eucalyptus leaves, provides prominent colour, whereas jute fabric, which was pretreated with different mordanting agents (e.g. alum, potassium dichromate and copper sulphate) does not. However, fabric dyed with ferrous sulphate yielded a dark ash colour. The probable reason of S2 yielding a brighter shade than S3 is the content of tannin and gallic acid in eucalyptus leaves, which has the capacity to colour the fabric without using mordanting agents. If alum was used as a mordanting agent, it reacted with dye molecules rather than enabling the fabric to absorb colour. On the other hand, ferrous sulphate intensifies the ability of tannin, gallic acid and quercetin to colour the fabric.

3.2 Colour coordinate value

All of the dyed jute fabrics were assessed under two light sources, i.e. D65 – artificial day light and TL84 – store light, using two methods: CIE $L^*a^*b^*$ and CIELCH. It is shown in Table 2 that lightness of only bleached fabric is high, whereas it is decreased in fabrics dyed with eucalyptus leaves, pre-mordanted with ferrous sulphate for both light sources. The value of redness/blueness is highest (9.64) for dyed fabrics,

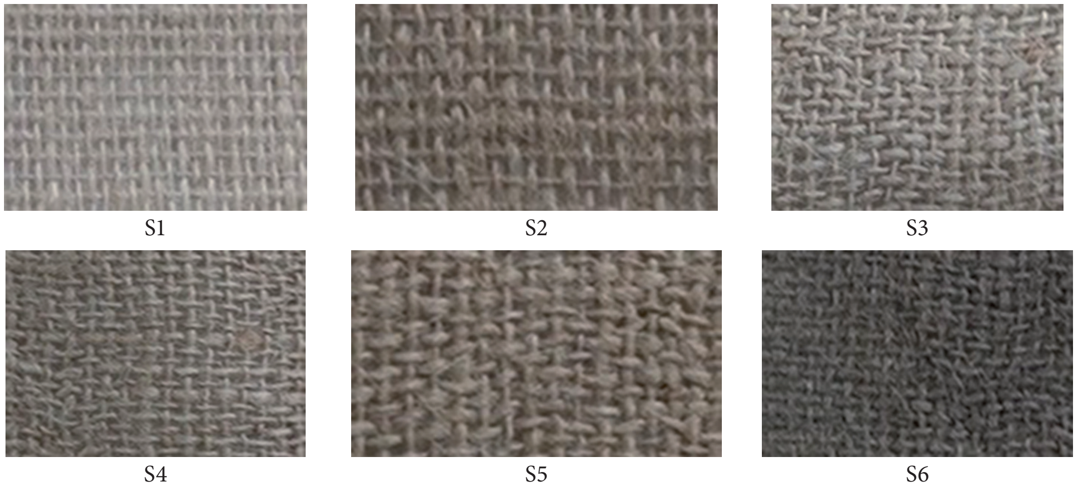

Figure 1: Pictorial view of dyed jute with eucalyptus leaves extract with and without mordant

Table 2: Colour coordinate value of all samples dyed with eucalyptus (average values and their standard deviations are given in brackets)

Sample	D65					LT84					ΔE
	L	*a*	*b*	*C*	*H*	*L*	*a*	*b*	*C*	*H*	
S1	60.71 (0.07)	4.92 (0.03)	16.89 (0.06)	17.59 (0.04)	73.77 (0.06)	61.72 (0.07)	4.97 (0.05)	19.17 (0.06)	19.80 (0.05)	75.48 (0.04)	2.49
S2	53.31 (0.03)	5.65 (0.02)	20.98 (0.05)	21.73 (0.03)	74.92 (0.06)	54.41 (0.04)	5.76 (0.05)	20.98 (0.05)	21.73 (0.03)	74.92 (0.07)	1.11
S3	57.26 (0.03)	5.94 (0.02)	20.44 (0.03)	21.29 (0.04)	73.80 (0.06)	58.41 (0.05)	6.00 (0.09)	23.17 (0.04)	23.93 (0.01)	75.48 (0.02)	2.96
S4	53.87 (0.04)	9.64 (0.02)	20.24 (0.02)	21.39 (0.07)	71.08 (0.05)	55.05 (0.09)	6.89 (0.06)	22.86 (0.06)	23.88 (0.06)	73.24 (0.03)	3.98
S5	51.12 (0.02)	6.71 (0.02)	24.04 (0.03)	24.96 (0.05)	74.41 (0.05)	52.45 (0.07)	6.56 (0.03)	27.24 (0.10)	28.02 (0.07)	76.45 (0.01)	3.47
S6	38.15 (0.02)	3.36 (0.02)	7.20 (0.02)	7.94 (0.03)	65.01 (0.04)	38.02 (0.04)	3.46 (0.03)	8.04 (0.04)	8.76 (0.03)	66.72 (0.03)	0.86

pre-mordanted with potassium dichromate. On the other hand, numerical value of *b*, *C* and *H* is higher for dyed fabric, pre-mordanted with ferrous sulphate. Moreover, it is clearly observed that the colour difference (0.86) of fabrics dyed with eucalyptus leaves and pre-mordanted with ferrous sulphate is lower than in all other dyed samples.

3.3 Evaluation of colour strength value

A colour strength depends on reflectance. Higher value of reflectance is, greater is the value of colour strength. As a result, a dark sample has a high colour strength, and a light shade fabric has lower K/S value. In this regard, fabric dyed with ferrous sulphate gives colour strength in the range of 9 to 21, since it yields dark colour rather than other mordants.

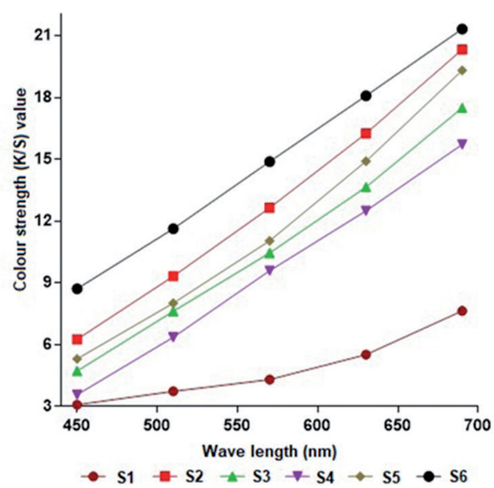

Figure 2: Colour strength value of each sample

3.4 Colour fastness to water

Fabric dyed with eucalyptus leaves yields outstanding water fastness. This was seen in all samples treated with or without mordants. The rating of colour fastness to water is 4 to 5 for both colour change and colour staining.

3.5 Colour fastness to wash

Although there is no variation of colour, change in wash fastness is similar for all samples (4–5), however, in terms of colour staining, wash fastness is better (4–5) for samples dyed with extracted dye solution before they were treated with alum, as the colour is lighter than in other samples. Fabric pre-mordanted with potassium dichromate exhibits comparatively lower fastness rate after dyeing with eucalyptus leaves extraction. Figure 3 also shows that the error bar of samples due to wash fastness in respect of colour change is zero, while colour staining fastness provided a standard error of 0.187.

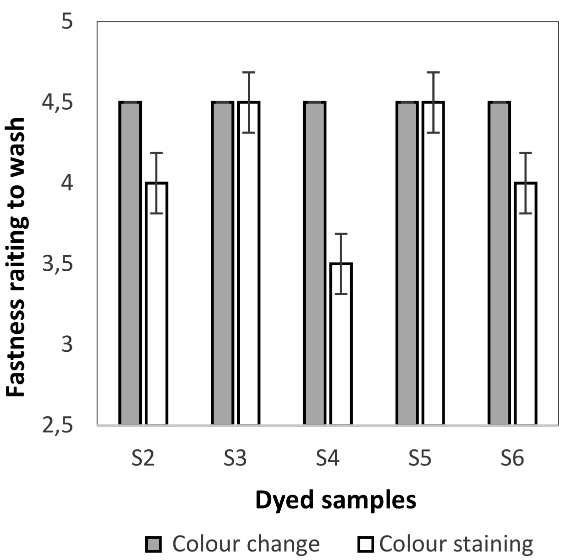

Figure 3: Colour fastness to wash of all dyed samples

3.6 Colour fastness to rubbing

All of the dyed fabric samples provide good (4) dry rubbing fastness, except fabrics pre-mordanted with $CuSO_4$, whereas wet rubbing fastness is fair to moderate (2–3) for every sample, except for the afore mentioned one. Figure 4 shows that there is only a slight error bar for both dry and wet rubbing fastness, as it has a standard error of 0.1, which means that there is no significant difference between the samples.

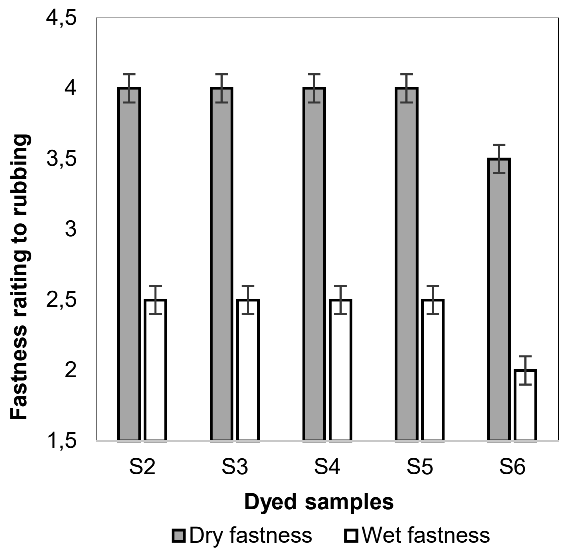

Figure 4: Colour fastness to rubbing of all dyed samples

3.7 Colour fastness to perspiration

Acid perspiration

Colour change of the acid perspiration rating is good (4–5) and similar for all samples, although colour staining of acid perspiration reveals moderate to good results for both samples pre- mordanted with $CuSO_4$ and $FeSO_4$. However, acid perspiration is not good for fabrics mordanted with alum. In addition to that, all the samples show an error bar of 0.187 standard error in respect of colour staining acid perspiration fastness.

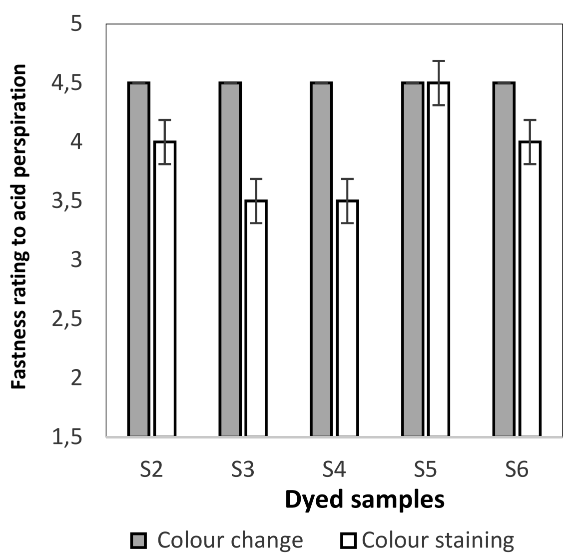

Figure 5: Colour fastness to acid perspiration of all dyed samples

Alkali perspiration

The colour fastness rating of alkali perspiration is identical (i.e. 4–5) for each dyed sample in respect to colour change. However, colour staining of alkali perspiration is better for fabrics pre-mordanted with $CuSO_4$. Like for acid perspiration, there is no standard error for samples of alkali perspiration due to colour change, but fastness rating of colour staining shows an error bar of 0.158 standard error.

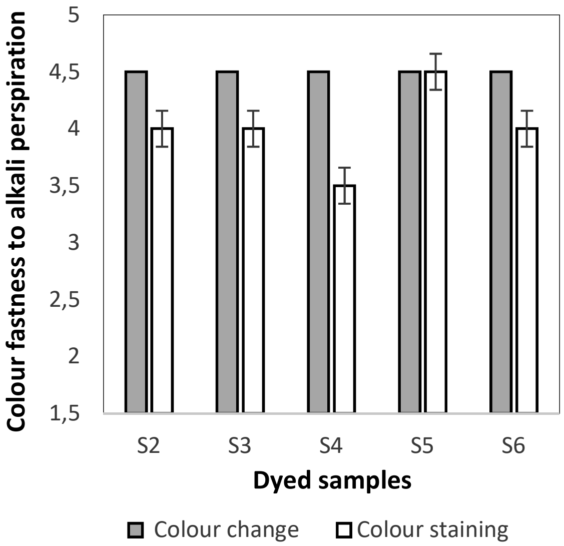

Figure 6: Colour fastness to alkali perspiration of all dyed samples

4 Conclusion

This empirical study shows prominent dyeing effects and their dyeing properties. Both, the visual and spectrophotometric results reveal that fabric dyed with extracted eucalyptus leaves gives bright shade when it is pre-mordanted with ferrous sulphate, as it has yielded higher colour strength. The colour difference value is also lower than in other dyed samples, which had better dyeing results. Dyed fabrics with eucalyptus leaves (without using any mordant) had good results that were very close to pre-mordanted fabric using ferrous sulphate. Although colour fastness properties of different dyed fabrics show fluctuating results, ranging from moderate to good grading. Overall, in terms of all colour fastness properties and dyeing properties, fabrics dyed without mordant and fabrics pre-mordanted with ferrous sulphate yielded better dyeing properties and higher quality.

Acknowledgement

The authors would like to thank Nice Fabrics for their endless support; providing their instruments and lab facilities. In addition to that, the authors pay special gratitude to the authority of the Northern University Bangladesh for their financial support.

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Snježana Kirin[1], Anica Hursa Šajatović[2]
[1] Karlovac University of Applied Sciences, Department of Safety and Protection, Trg J.J. Strossmayera 9, 47000 Karlovac, Croatia
[2] University of Zagreb Faculty of Textile Technology, Department of Clothing Technology, Prilaz baruna Filipovića 28a, 10000 Zagreb, Croatia

Determination of Working Methods and Normal Times of Technological Sewing Operation using MTM System
Določitev metod dela in časovnih normativov operacij tehnološkega šivanja s sistemom MTM

Original scientific article/*Izvirni znanstveni članek*
Received/*Prispelo* 4-2020 • Accepted/*Sprejeto 7-2020*

Corresponding author/*Korespondenčna avtorica:*
Assoc Prof dr. Anica Hursa Šajatović
E-mail: anica.hursa@ttf.unizg.hr
Phone: +385 1 37 12 551
ORCID: 0000-0002-3394-3115

Abstract
Working processes in the technological sewing process are performed on machine systems characterized by machine-manual work, where the worker and the machine work simultaneously. Such a work system requires a great deal of responsibility in terms of quality, quantity, and the accurate and timely execution of tasks, which requires the quick and accurate response and extremely good psychomotor and visual skills of workers. This paper presents the process of determining the working method and normal times for the technological operation of runstitching women's blouse collars, which includes the design of an ergonomically designed workplace, the selection and technical equipment of the universal sewing machine and the determination of the optimal work method and normal times using the Methods-Time Measurement (MTM) system. The research results obtained indicate that the technical equipment of a universal sewing machine has a significant impact on the structure of the technological sewing operation and the working method, i.e. the number of auxiliary manual technological suboperations. Improving technical equipment, i.e. increasing the number of automated functions used on a universal sewing machine, reduces the number of auxiliary manual suboperations, reduces the time required to perform the technological operation and increases work productivity.
Keywords: technological operations of garment sewing, work method, determination of normal times, MTM system

Izvleček
Delovni proces v tehnološkem postopku šivanja se izvaja na strojnih sistemih, za katere je značilno strojno-ročno delo, pri čemer delavec in stroj delata sočasno. Takšen delovni sistem zahteva veliko odgovornosti glede kakovosti, količine ter natančnega in pravočasnega izvajanja nalog. To zahteva hitre in natančne reakcije ter izredno dobre psihomotorične in vizualne spretnosti delavcev. V članku je predstavljen postopek določanja metode dela in normiranih časov tehnološke operacije šivanja ovratnika ženske bluze. Ta vključuje zasnovo ergonomsko oblikovanega delovnega mesta, izbiro tehnološke opreme univerzalnega šivalnega stroja in določitev optimalne metode dela in normiranega časa z metodo merjenja časa (sistem MTM). Rezultati raziskave kažejo, da tehnična oprema univerzalnega šivalnega stroja pomembno vpliva na strukturo tehnološkega postopka šivanja in na način dela, tj. na število pomožnih ročnih tehnoloških podo-

peracij. Izboljšanje tehnološke opreme in posledično povečanje števila samodejnih operacij na univerzalnem šivalnem stroju zmanjša število pomožnih ročnih podoperacij in čas izvajanja tehnološke operacije ter poveča produktivnost dela.
Ključne besede: tehnološke operacije šivanja oblačil, metoda dela, določanje normirnih časov, sistem MTM

1 Introduction

The garment industry is labour-intensive and represents the final stage of textile processing. It is responsible for the overall quality of clothing, not only in the area of production, but also in terms of the quality of basic and built-in parts.

For many years, the production of clothing has been focused on small production series of models, different colours, patterns and clothing sizes, high production quality, short delivery times, and the reduction of all production costs. For the successful business of the garment industry, modern production processes are organized according to the Quick Response (QR) strategy, the task of which is to respond quickly to market demand, and the Just-in-Time (JIT) technology strategy aimed at the prudent planning of production time. The JIT strategy organizes technological preparations for the faster placement of clothing on the market, and operations on the principle of profit-making on the basis of cost reduction [1, 2].

According to the organization of the work process, technological sewing operations are considered an assembly (piece) type of work process with a linear method of workplace installation. At their workplaces, workers perform technological operations of similar characteristics, leading to a higher degree of utilization of machines and devices, the improved transport of materials and workpieces through the production line, the reduction of production times, and thus production cycles. This in turn, leads to an increase in the production capacity of each workplace, production lines and systems [3, 4]. Research on the structure of working hours over the course of one working day (450 minutes) in the technological sewing process indicates that the worker spends 20 to 30% of their time for technological machine-manual sewing suboperations $(t_t)_{ar}$ and 60 to 70% of their time for auxiliary manual suboperations $(t_p)_r$, while about 10% (45 minutes) of time is spent on non-productive activities [5, 6].

According to the performance structure, the technological sewing operation comprises the following suboperations: taking the workpiece, assembly, positioning, suboperations during sewing breaks and putting down the workpiece as well as the technological machine-manual suboperations of sewing (Figure 1) [7, 8].

Technological sewing operations have short execution cycles of 15 to 60 seconds, a high degree of repetitiveness with a considerable psychophysical workload on the worker caused by a static sitting load, a high degree of eye focus, short manual movements and the frequent performance of combined and simultaneous movements. An ergonomic and functionally designed workplace and the determination of optimal work methods with corresponding time norms are required for the successful performance of the technological operation. This will facilitate the favourable structure of the technological operation, with the increased use of machines and increased hourly production, while reducing the psychophysical workload on workers, increasing productivity and production quality and reducing production costs [9, 10].

Systems of predetermined normal times are based on the principle that the work process can be broken down to the level of basic motions, which can determine work methods and production time. The most commonly used systems of predetermined normal times are: Motion Time Analysis (MTA), Work Factor (WF), Methods-Time Measurement (MTM), Basic Motion- Time (BMT) study, Dimensional Motion Times (DMT) and Master Clerical Data (MCD). These systems are also referred to in literature as synthetic time systems.

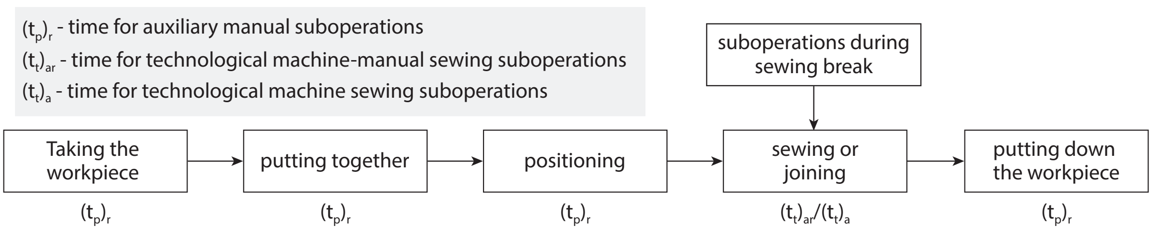


Figure 1: Structure of the technological sewing operation [7, 8]

Available on the market today are software solutions that are used for the quick and easy determination of normal times using predetermined motion time systems, and for the better organization of production process, the calculation of prices and offers, workflow optimization, etc. The MTM organization has developed several software solutions [11] such as TICON, the standard software for industrial engineering, and MTM-EasyTime, which are based on the MTM-1 system. The MTM Association Benelux [12] upholds the professional standards of training and research. That organisation developed the following MTM-software: TiCon© (Time Control), as support software for MTM-building block-systems (UAS, MEK, SDB, MTM-1 and MTM-2), EAWSdigital (Ergonomic Assessment WorkSheet) and ProKondigital (Productiegeoriënteerde Konstructie). In addition, the TMU CALCULATOR® (MTM Software / MTM App) processes predetermined time systems such as MTM-1 [13].

Workplace design includes adjusting the seat height, the height and size of the work surface, foot pedal position, and the distance of the seat from the edge of the work surface to the physical measurements of the worker. This results in a favourable working posture with the anterior flexion of the spine of up to 15° and the anterior flexion of the head and neck of up to 30°, with additional eye travel of up to 10°, which ensures a vision field with a viewing angle of ±1°. In this way, the high visual acuity required to accurately perform the technological sewing operation is achieved [14, 15].

This paper presents an ergonomically designed workplace for the technological operation of runstitching women's blouse collars. Working methods for performing that technological operation, taking into account the technical equipment of the universal sewing machine, were developed and described. Two levels of technical equipment of the universal sewing machine were considered:

Level 1: non-equipped universal sewing machine (manual seam beginning and end seam bartacking, manual cutting of thread); and level 2: universal sewing machine with programmed functions of tucking the beginning and end of seam, needle positioning in the specified position and the automatic cutting of thread.

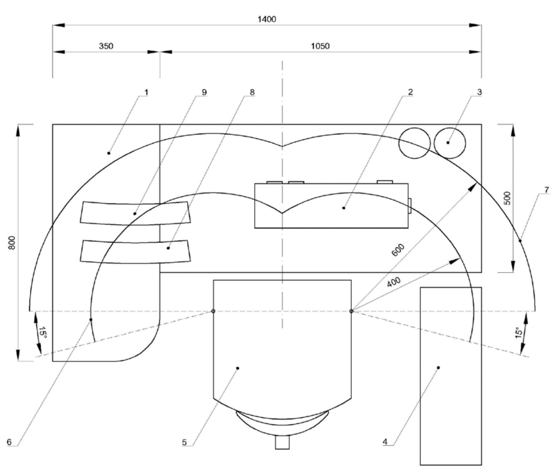
Working method analysis and the determination of time norms of the technological operation of runstitching women's blouse collars were performed using the MTM system.

2 Materials and methods

In the experimental part of this paper, working methods for the technological operation of runstitching women's blouse collars were defined and designed, depending on the technical equipment of the sewing machine. For this purpose, a workplace was designed, a universal sewing machine was selected, and the working method and performance time were determined using the MTM system, while the RAV and ZAK methods were used to determine the normal time of the machine-manual sewing suboperation.

2.1 Designed workplace

A universal BROTHER DB2-B755-403A Mark III sewing machine with a work surface dimension of 500 mm x 1400 mm (Figure 2) was selected. The



1 – work surface of the sewing machine
2 – head of the universal sewing machine
3 – sewing thread stand
4 – stand for putting down the workpiece
5 – industrial chair
6 – normal reach zone
7 – maximum reach zone
8 – lower part of the collar
9 – upper part of the collar

Figure 2: Designed workplace for the technological operation of runstitching women's blouse collars

workpiece bundles were of a medium size (dimensions 36 cm x 7 cm) and were located on the work surface of the sewing machine in the normal reach zone.

The workplace was designed according to the worker's body height (160 cm), while the sitting height (50 cm) was determined according to the popliteal length of the lower leg (43 cm) with an allowance for footwear (2 cm) and the sewing machine's pedal height (5 cm). The distance of the torso from the edge of the work surface was 15 to 20 cm, while the height of the work surface was 10 to 15 cm higher than the thigh thickness. This posture allowed the work to be performed with anterior head flexion in a comfortable posture up to a maximum of 30° with an eye distance of 30 to 40 cm from the central working sewing space, thereby achieving the high visual acuity required for the accurate technological operation. The workpiece or women's blouse collar dimension of 36 cm x7 cm is shown in Figure 3. The runstitching of women's blouse collars was performed in three segments, where segments A and C (7 cm) had 34 stitches in the seam, and segment B (36 cm) had 144 stitches in the seam. The runstitching of women's blouse collars was performed with sewing stitch type 301 and a stitch density of 4 cm.

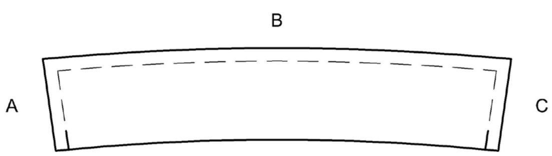


Figure 3: Women's blouse collar (36 cm x7 cm) with marked sewing segments

The designed working method for the technological operation of runstitching women's blouse collars included taking the workpiece from the first bundle, moving the workpiece to the work zone and releasing it onto the work surface of the sewing machine. The worker reached out and took the workpiece from the second bundle, moved it to the work zone and placed it on the first workpiece (assembly). The worker then performed positioning under the machine sewing needle while simultaneously lifting the presser foot. The worker sewed the first segment (Figure 3, segment A) with seam beginning bartacking. After sewing the first segment, the worker turned the workpiece to change the sewing direction, aligned the workpiece and sewed the second segment (Figure 3, segment B). The workpiece was turned again due to the change of the sewing direction, and the third segment (Figure 3, segment C) was sewn with the seam end bartacking and the thread was cut off. After sewing, the worker moved the workpiece to the movable stand located on the right.

2.2 Sewing machine

A universal BROTHER DB2-B755-403A Mark III sewing machine was selected for the technological operation of runstitching women's blouse collars. It is a single needle, double lockstitch sewing machine. The workpiece is moved by the bottom feed. The sewing machine is equipped with process microcomputer model F-100 which, with the help of a built-in servomotor and other additional devices, enables the programmed performance of complex segments of technological processes. The most important automatic functions are needle positioning above or in the throat plate, the automatic tucking of the beginning and the end of the seam, automatic thread cutting, and the automatic lifting of the presser foot at the end of the sewing segment or technological operation, with the possibility of programming the nominal stitch speed of the sewing machine. For research purposes, the sewing machine was programmed using a process microcomputer, where two levels of equipment were selected.

Level 1 (technically non-equipped universal sewing machine):

- the lifting and lowering of the presser foot were performed using a knee lever mechanism;
- the tucking of the beginning and end of the seam was performed using a manual lever mechanism according to the worker's experience with an unequal number of stitches;
- the machine sewing needle was in an unspecified position after the break or end of sewing; and
- the thread was cut off after the sewing process using scissors and the workpiece was putting down.

Level 2 (technically equipped sewing machine):

- the electromagnetic lifting of the presser foot was determined according to the function of the pedal movement;
- the tucking of the beginning and end of the seam was programmed to 3 stitches;
- the machine sewing needle was set in its programmed position; and
- the automatic cutting of the thread was performed using a mechanism activated by the pedal movement.

2.3 Methods-Time Measurement (MTM-1) system

By studying various working methods, through the systematic filming of a large number of trained workers in various production processes, and using detailed analysis and methods of motion studies based on the breakdown of work to the level of basic movements, H.B. Maynard, G.J. Stegemerten and J.L. Schwab established the basic MTM-1 system, which can be used for assembly processes [16].

The basic MTM-1 system provides a detailed description of working methods and an analysis of manual operations up to the level of basic motions. The MTM-1 system consists of nine basic motions of fingers, hands and arms (Reach – R, Move – M, Turn – T, Crank – C, Apply Pressure – AP, Grasp – G, Release – RL, Position – P, Disengage – D), two eye motions (Eye Focus – EF, Eye Travel – ET) and ten motions of the feet, legs and body (Foot Motion – FM, Leg Motion – LM, Sidestep – SS, Turn Body – TB, Bend – B, Stoop – S, Kneel – K, Sit – SIT, Stand up – STD, Walk – W). The times for basic motions are summarized in tables, depending on the variables of motions (length, case and type of motion, mass, size and shape of the object to be handled, etc.), and their combination results in the required time of a suboperation or technological operation. The times listed in the tables are given for the average trained worker of normal mental, psychological and physical abilities, and represent normal time (t_n). The time unit of the MTM system is TMU (Time Measurement Unit), which is 0.00001 hours or 0.036 seconds. Up to 400 minutes are required for the analysis of technological operations and suboperations up to the level of basic motions using the MTM-1 system, and to describe one minute of the work process [17, 18].

Primarily arm, hand and finger motions are used in the technological sewing process: reach (R), grasp (G), move (M), release (RL), position (P), turn (T) and apply pressure (AP). Also used are eye motions: eye focus (EF) and eye travel (ET), as well as body, leg and foot motions: foot motions (FM) and leg motions (LM) [17, 19].

2.4 Determination of machine-manual sewing times

When performing machine-manual technological sewing suboperations and guiding the workpiece, it is necessary to maintain three degrees of freedom of movement: seam distance from the edges of the workpiece, alignment of the workpiece and monitoring the seam curvature for a seam allowance of ±1 mm [18]. The time of machine-manual sewing suboperations depends on nominal stitch speed, seam curvature, specific stitch density, total length of the sewn seam, number of segments and the equipment of the sewing machine with auxiliary devices. Mathematical models obtained through the systematic investigation of sewing process parameters using the patented measuring equipment for measuring process parameters (MMPP) developed at the University of Zagreb, Faculty of Textile Technology in the Department of Clothing Technology were used to determine the machine-manual normal times of the technological sewing suboperation of straight and curved seams [20, 21]. The applied mathematical models give the dependence of the normal times of machine-manual suboperations on the variable values of process parameters:

- nominal stitch speed of the sewing machine (v_n/rpm): 1000–7000;
- stitch number in the segment (B_u): 10–300;
- correction factor of the sewing machine (K_1): 1.00–1.15; and
- coefficient of radius of the seam curvature (r_z/mm): 20–3000.

Normal times for straight seams (RAV) were determined according to expression (1) and for curved seams (ZAK) according to formulas (2):

$$t_{arRAV} = \left\{ \begin{matrix} B_u[0.227 - 0.025\, ln(v_n)] \\ +0.334 \end{matrix} \right\} K_1 \tag{1}$$

$$\begin{aligned} t_{arZAK} = &\left\{ \begin{matrix} B_u[0.227 - 0.025\, ln(v_n)] \\ +0.334 \end{matrix} \right\} \cdot \\ &K_1\, [3.12 - 0.3\, ln(r_z)]\} \end{aligned} \tag{2}$$

A computer program [22, 23], which is used to calculate the normal time of the machine-manual sewing suboperation in different time units (s, TMU, min, h), was developed for these mathematical models.

3 Results and discussion

A workplace was designed (Figure 2) for the technological operation of runstitching women's blouse collars on the above-described universal sewing machine, while the working method was defined and designed, and an analysis of the suboperation to the level of motion using the MTM system was performed. The time of machine-manual technological sewing operations was determined using the RAV and ZAK methods. In the case of the technically non-equipped sewing machine (level 1), the technological operation of runstitching women's blouse collars comprised the following technological suboperations:

1. an individual taking the workpiece from the first bundle with one hand, moving it to the other hand and releasing it in the central work zone, and an individual taking the workpiece from the second bundle with one hand and moving it to the other hand;
2. assembly;
3. positioning under the needle (lifting the presser foot using the leg motion (LM) and lifting the sewing needle into the upper position with the right hand using the wharf of the main shaft);
4. sewing the seam in three segments by aligning the edges after sewing segments A and B, and by tucking the beginning and end of the seam using the seam bartacking mechanism lever;
5. cutting of the thread with scissors;
6. putting down the workpiece.

Table 1 presents an analysis of technological suboperations to the level of motions using the MTM system for the technically non-equipped universal sewing machine (level 1).

Table 1: Working method and the analysis of technological suboperations to the level of motions using the MTM system for the technically non-equipped universal sewing machine (level 1)

No.	Left hand movement description	Symbol	TMU	Symbol	Right hand movement description
1					
1 TAKING THE WORKPIECE					
1.1	Reach for the bundle	mR30B	8.5		
1.2.	Grasp the workpiece	G5/G2	5.6		
1.3.	Lift the workpiece	M10Bm	4.3		
1.4.	Move to the central work zone	mM30B	8.5		
1.5.			5.6	G3	Grasp the workpiece
1.6.	Release the workpiece	RL1	2.0	(RL1)	Release the workpiece
1.7.	Reach for the bundle	mR35B	11.4		
1.8.	Grasp the workpiece	G5/G2	5.6		
1.9.	Lift the workpiece	M10Bm	4.3		
1.10.	Move to the central work zone	(mM35B)	11.7	R10A G5/G2	Reach for the workpiece in the left hand and grasp it
1.11.	Extend the arm along the workpiece	R10E	6.8		
		ΣTMU (s)	**74.3 (2.68)**		
2 ASSEMBLING THE EDGES OF WORKPIECES BY CHANGING THE GRIP					
2.1.	Move the workpiece to the corner	M7C	6.4	(M7C)	Move the workpiece to the corner
2.2.			5.6	P1SE	Precisely put on the first corner
2.3.	Contact grasp	(G5)	3.2	R4E	Pull the index finger from under the workpiece
2.4.	Pull along the edge of the workpiece to the other corner	R35B	14.2		
2.5.	Grasp	G1B	3.5		
2.6.	Precisely move to the other corner	M5C	5.2		
2.7.	Precisely put on the other corner	P1SE	5.6		
2.8.	Pull the index finger from under the workpiece	R4E	3.2		
2.9.	Additional grasping	G2	5.6	(G2)	Additional grasping
		ΣTMU (s)	**52.5 (1.89)**		

No.	Left hand movement description	Symbol	TMU	Symbol	Right hand movement description
3 POSITIONING THE WORKPIECE					
3.1.	Move to the presser foot	M10B	6.8	(1/2 LM)	Lift the presser foot using the knee lever
3.2.			11.3	R40A	Reach for the main shaft
3.3.			5.6	G5/G2	Grasp the main shaft
3.4.			8.4	M6B/AF	Turn the main shaft
3.5.			0.0	RL2	Release the main shaft
3.6.			14.1	R40E	Return the hand to the workpiece
3.7.	Move to the needle	M6C	5.8		
3.8.	Position under the needle	P1SE	5.6		
3.9.			3.6	(1/2 LM)	Lower the presser foot using the knee lever
		ΣTMU (s)	**61.2 (2.20)**		
4 TUCKING THE BEGINNING OF THE SEAM					
4.1.			9.5	R30A	Reach for the lever
4.2.			0.0	G5	Grasp the lever
4.3.	Activate the pedal	FM	8.5	(M4A/AF)	Push down on the lever
4.4.			0.0	RL2	Release the lever
4.5.			11.7	R30E	Return the hand to the workpiece
		ΣTMU (s)	**29.7 (1.07)**		
5 SEWING THE FIRST SEGMENT					
5.1.	Sew segment A	t_{ar}	60.6		
		ΣTMU (s)	**60.6 (2.18)**		
6 POSITIONING THE NEEDLE INTO THE LOWER POSITION, TURNING, ALIGNING					
6.1.	Deactivate the pedal	(FM)	11.3	R40A	Reach for the main shaft
6.2.			5.6	G5/G2	Grasp the main shaft
6.3.			8.4	M6B/AF	Turn the main shaft
6.4.			3.6	1/2 LM	Lift the presser foot using the knee lever
6.5.	Turn the workpiece	M25C	13.4	(R30E)	Return the hand to the workpiece
6.6.	Kinematic reaction	t_{rr}	4.0		
6.7.			3.6	1/2 LM	Lower the presser foot using the knee lever
6.8.			2.0	RL1	Release the workpiece
6.9.	Contact grasp	(G5)	11.3	mR35E	Reach the hand to another place
6.10.			2.0	G1A	Grasp the workpiece
6.11.			11.4	M6C/ P1SE	Parallel placing and joining
		ΣTMU (s)	**76.6 (2.76)**		
7 SEWING THE SECOND SEGMENT					
7.1.	Activate the pedal	FM	8.5		
7.2.	Sew segment B	t_{ar}	108.1		
		ΣTMU (s)	**116.6 (4.20)**		
8 POSITIONING THE NEEDLE INTO THE LOWER POSITION, TURNING, ALIGNING					
8.1.	Deactivate the pedal	(FM)	11.3	R40A	Reach for the main shaft
8.2.			5.6	G5/G2	Grasp the main shaft
8.3.			8.4	M6B/AF	Turn the main shaft

No.	Left hand movement description	Symbol	TMU	Symbol	Right hand movement description
8.4.			3.6	1/2 LM	Lift the presser foot using the knee lever
8.5.	Turn the workpiece	M25C	13.4	(R30B)	Return the hand to the workpiece
8.6.	Kinematic reaction	t_{rr}	4.0		
8.7.			3.6	1/2 LM	Lower the presser foot using the knee lever
8.8.			2.0	RL1	Release the workpiece
8.9.			4.6	mR8E	Reach the hand to another place
8.10.			2.0	G1A	Grasp the workpiece
8.11.			11.4	M6C/ P1SE	Parallel placing and joining
		ΣTMU (s)	**69.9 (2.51)**		
9 SEWING THE THIRD SEGMENT					
9.1.	Activate the pedal	FM	8.5		
9.2.	Sew segment C	t_{ar}	60.6		
		ΣTMU (s)	**69.1 (2.49)**		
10 TUCKING THE END OF THE SEAM					
10.1.			9.5	R30A	Reach for the lever
10.2.			0.0	G5	Grasp the lever
10.3.			8.5	(M4A/AF)	Push down on the lever
10.4.			0.0	RL2	Release the lever
10.5.			12.8	R30B	Return the hand to the workpiece
10.6.	Deactivate the pedal		8.5	FM	
		ΣTMU (s)	**39.3 (1.41)**		
11 CUTTING OF THE THREAD WITH SCISSORS					
11.1.			3.6	1/2 LM	Lift the presser foot using the knee lever
11.2.			11.3	R40A	Reach for the main shaft
11.3.			5.6	G5/G2	Grasp the main shaft
11.4.			8.4	M6B/AF	Move with pressing
11.5.	Pull the workpiece from under the needle	M10B	6.8		
11.6.			11.4	R25B	Reach for the scissors
11.7.			5.6	G5/G2	Grasp the scissors
11.8.			10.5	M20B	Move the scissors into the work zone
11.9.			5.8	M6C	Move the scissors to the thread
11.10.			(2.0)	(M2A)	Open the scissors simultaneously
11.11.			3.4	AF	Press the scissors blades
11.12.			(2.0)	(M2A)	Cut the thread simultaneously
11.13.			11.2	M25A	Put down the scissors
11.14.			2.0	RL1	Release the scissors
11.15.			10.0	R25E	Return the hand to the workpiece
		ΣTMU (s)	**99.1 (3.57)**		
12 PUTTING DOWN THE WORKPIECE WITH THE RIGHT HAND					
12.1.			6.3	R10B	Take the workpiece
12.2.	Release the workpiece	(RL1)	2.0	G1A	Grasp the workpiece
12.3.			6.8	M10B	Lift the workpiece

No.	Left hand movement description	Symbol	TMU	Symbol	Right hand movement description
12.4.			18.0	M50B	Lay off the workpiece
12.5.			2.0	RL1	Release the workpiece
12.6.			14.7	R50Em	Return the hand to balanced position
		ΣTMU (s)	**49.8 (1.79)**		
TOTAL: ΣTMU (s) = 798.7 (28.75)					

Based on the established working method using the MTM system, the normal time for performing the technological operation of runstitching women's blouse collars for the technically non-equipped sewing machine was 798.7 TMU (28.75 s).

In the case of a technically equipped universal sewing machine, the technological operation of runstitching women's blouse collars comprises the following technological suboperations:

1. an individual taking the workpiece from the first bundle with one hand, moving it to the other hand and releasing it in the central work zone, and an individual taking the workpiece from the second bundle with one hand and moving it to the other hand;
2. assembly;
3. positioning under the sewing needle (lifting the presser foot and the sewing needle by foot movement);
4. sewing the seam in three segments by aligning the edges after sewing segments A and B, and automatic tucking the beginning and end of the seam, and cutting of the thread;
5. putting down the workpiece.

Table 2 presents an analysis of technological suboperations to the level of motions using the MTM system for the technically equipped universal sewing machine (level 2). Some technological suboperations are similar for both working methods (levels 1 and 2 of technically equipped machine). For this reason, Table 2 illustrates the entire MTM analysis for different technological suboperations.

Table 2: Working method and analysis of technological suboperations to the level of motions using the MTM system for the technically equipped sewing machine (level 2)

No.	Left hand movement description	Symbol	TMU	Symbol	Right hand movement description
1 TAKING THE WORKPIECE – the same as for the level 1 (see Table 1)					
		ΣTMU (s)	**74.3 (2.68)**		
2 ASSEMBLING THE EDGES OF WORKPIECES BY CHANGING THE GRIP – the same as for level 1 (see Table 1)					
		ΣTMU (s)	**52.5 (1.89)**		
3 POSITIONING THE WORKPIECE					
3.1.	Move to the presser foot	(M10B)	8.5	FM	Lift the presser foot using the pedal
3.2.	Move to the needle	M6C	5.8		
3.3.	Position under the needle	P1SE	5.6		
3.4.			8.5	FM	Lower the presser foot using the pedal
		ΣTMU(s)	**28.4 (1.02)**		
4 SEWING WITH AUTOMATIC TUCKING THE BEGINNING AND END OF THE SEAM AND CUTTING OFF THE THREAD					
4.1	Activate the pedal	FM	8.5		
4.2.	Sew segment A	t_{ar}	60.6		
4.3.	Lift the presser foot	FM	8.5		
4.4.	Turn the workpiece	M25C	13.4		
4.5.			2.0	RL1	Release the workpiece
4.6.	Contact grasp	(G5)	11.3	mR35E	Reach the hand to another place
4.7.			2.0	G1A	Grasp the workpiece
4.8.			11.4	M6C/ P1SE	Parallel placing and joining

No.	Left hand movement description	Symbol	TMU	Symbol	Right hand movement description
4.9.	Kinematic reaction	t_{rr}	4.0		
4.10.	Lower the presser foot and activate the pedal	FM	8.5		
4.11.	Sew segment B	t_{ar}	108.1		
4.12.	Lift the presser foot	FM	8.5		
4.13.	Turn the workpiece	M25C	13.4		
4.14.	Kinematic reaction	t_{rr}	4.0		
4.15.	Lower the presser foot and activate the pedal	FM	8.5		
4.16.			2.0	RL1	Release the workpiece
4.17.			11.3	mR35E	Reach the hand to another place
4.18.			2.0	G1A	Grasp the workpiece
4.19.			11.4	M6C/ P1SE	Parallel placing and joining
4.20.	Activate the pedal	FM	8.5		
4.21.	Sew segment C	t_{ar}	60.6		
4.22.	Foot motion	FM	8.5		
4.23.	Reaction time of lifting the presser foot and the needle, and automatic cutting off the thread	t_{aok}	4.0		
4.24.	Deactivate the pedal	1/2 FM	4.3		
		ΣTMU (s)	**385.3 (13.87)**		
5. PUTTING DOWN THE WORKPIECE WITH THE RIGHT HAND – the same as for the level 1 (see Table 1)					
		ΣTMU (s)	**49.8 (1.79)**		
TOTAL ΣTMU (s) = 590.3 (21.25)					

The normal time offor performing the designed technological operation of runstitching women's blouse collars on the technically equipped sewing machine was 590.3 TMU (21.25 s).

The conducted research dealt with the working method and the normal time for performing the designed technological operation of runstitching women's blouse collars using the technically non-equipped (level 1) and technically equipped (level 2) universal sewing machine. In this way, it was possible to compare the structure of the technological operation with the technological suboperations and motions for two different working methods already in the design phase of the production system.

Based on the obtained results, it was determined that the normal time for the technological operation of runstitching women's blouse collars on the technically non-equipped universal sewing machine was 28.75 seconds (798.7 TMU), while the normal time for the technically equipped universal sewing machine was 21.25 seconds (590.3 TMU), meaning that time decreased by 26.1%. According to the above, it can be concluded that the working method and the normal time depend on the technical equipment of the sewing machine, if the same worker works in an equally designed workplace. When performing the technological operation on the technically non-equipped universal sewing machine, the worker performs several auxiliary manual motions, as can be seen from the comparison of the motion sets for both methods (Table 3).

Table 3 shows that on the technically equipped sewing machine with automated functions the following sets of motions are eliminated:

- tucking the beginning and end of the seam;
- positioning the needle into the lower position during sewing break due to the change of the sewing direction; and
- manual cutting of the thread with scissors.

The machine-manual time of the technological sewing suboperation was calculated according to formulas (1) and (2). The resulting times are the same for both working methods and amounted to 8.25 seconds (229.3 TMU) for all three segments. The set of motions for positioning the workpiece differs de-

Table 3: Comparison of the used sets of motions for performing auxiliary manual suboperations in the technological operation of runstitching women's blouse collars on the technically non-equipped and equipped sewing machine

Description of the set of motions	Level of the technical equipment of the universal sewing machine	
	Level I	Level II
Taking the workpiece	✓	✓
Assembling the edges of workpieces by changing the grip	✓	✓
Positioning the workpiece	✓	✓
Tucking the beginning of the seam	✓	-
Positioning the needle into the lower position, turning, aligning	✓	-
Tucking the end of the seam	✓	-
Cutting of the thread using the scissors	✓	-
Putting down the workpiece with the right hand	✓	✓

pending on the level of technical equipment of the sewing machine. In the case of the technically non-equipped sewing machine, the presser foot is lifted by the thigh motion and by pushing down the knee lever (1/2 LM). The worker reaches the right hand to the shaft, lifts the sewing needle into the upper position (motions 3.2 to 3.6 in Table 1), and moves the workpiece (M6C) and positions it under the needle (P1SE), and lowers the presser foot (1/2 LM), taking a total of 2.20 seconds (61.2 TMU). In the case of the technically equipped sewing machine, the workpiece is moved to the presser foot (M10B), while the presser foot and the sewing needle are simultaneously lifted by the foot pushing down the pedal (FM). The workpiece is moved (M6C) and positioned under the needle (P1SE), the presser foot is lowered by the foot (FM), taking a total of 1.02 seconds (28.4 TMU), meaning that the time was reduced by 55.5%.

In the case of the technically non-equipped sewing machine, tucking the beginning and end of the seam during the technological sewing suboperation is performed using the bartacking mechanism lever with the following set of motions 4.1 to 4.5 (Table 1), with a total duration of 1.07 seconds (29.7 TMU). In addition, the number of stitches for tucking the beginning and end of seam is programmed using a process microcomputer on the technically equipped sewing machine.

During the sewing break, due to a direction change on the technically non-equipped sewing machine before turning the workpiece, it is necessary to move the needle into the lower position using the wharf, which is done using a right-hand motion. The knee lever is used to lift the presser foot and the motion set for the entire suboperation is 6.1 to 6.5 (Table 1) with a duration of 1.47 seconds (42.3 TMU). In the case of the technically equipped universal sewing machine, the placement of the needle into the appropriate position is programmed using a process microcomputer. The cutting of the thread on the technically non-equipped sewing machine is done using hand scissors and the set of motions 11.1 to 11.15 (Table 1) with a duration of 3.57 seconds (99.1 TMU). The same operation is performed on the technically equipped sewing machine by pushing down the pedal with a foot motion (FM), which lifts the needle and the presser foot into the upper position activating the mechanism for cutting the thread with a duration of 0.60 seconds (16.8 TMU).

The analysed technological operation of runstitching women's blouse collars has a similar working method as technological operations of runstitching the pocket flap or runstitching women's blouse cuffs or men's shirt cuffs. The difference between these technological operations lies in the method of taking and assembling the workpiece because cutting parts are smaller, and the time of machine-manual suboperations, which are calculated according to the formulas for the RAV and ZAK methods as the seam lengths, is also less. When the runstitching of the cuff or the pocket is performed, assembly is performed at the sewing beginning and during the technological sewing operation, and no additional alignment of the workpiece is required.

A comparison of the working methods indicates that the technological operation of sewing (level 1) is performed in the sagittal and frontal planes (tucking the beginning of the seam, positioning the needle into the lower or upper position and cutting of the thread using scissors), thus interrupting the uniform rhythm of performance, which requires a higher degree of movement coordination. In the working method of level 2, the technological sewing operation is performed in the sagittal plane, which enables a uniform rhythm of performance and a reduced workload on workers.

This scientific approach also enables to formulation of logical sets of individual suboperations based on the analysis of basic movements. Combining logical sets formulated and defined using the MMPP method, the optimal working methods of the technological operations with normal times can be determined in advance already in the design phase of the sewing process based on the designed workplace.

4 Conclusion

The application of the MTM system in the technological processes of clothing production facilitates the identification, development and preparation of optimal working methods before production starts, the rationalization of existing procedures and working methods, and the determination of actual norms with respect to working staff and installed equipment.

On the basis of the MTM analysis carried out and the identified suboperations in the structure of the technological operation of runstitching women's blouse collars at the designed workplace using a universal sewing machine, it can be concluded that a higher level of technical equipment of sewing machines enables the following:

- the optimal structure of the technological sewing operation;
- the optimal working method with proper time norms;
- the elimination of some motions in technological suboperations, and the replacement of others with motions that are easier to perform; and
- a reduction in the time required to perform the technological operation and increased labour productivity.

The obtained research results show that a higher level of technical equipment of sewing machines results in a higher degree of utilization of those machines and higher productivity. The research presented in this paper has proven the appropriateness of the use of the MTM system, and the RAV and ZAK methods to determine the optimal working methods and corresponding time norms of the technological operation. This research can be very useful in real clothing production processes because the MTM analysis and defined logical sets of movements for suboperations in the technological process of sewing with performance times can provide prompt normal times for the technological operation. Moreover, the use of MTM software as an application or calculator makes it possible to determine normal time for the technological operation in the production process, and facilitates the calculation of prices and offers, the better organization of the production process, workflow optimization, etc.

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Blaženka Brlobašić Šajatović, Darko Ujević, Slavenka Petrak
University of Zagreb, Faculty of Textile Technology, Department of Clothing Technology, Zagreb, 10000, Croatia

Body Proportions of Football Players and the Untrained Population, and the Impact on the fit of the Trousers

Vpliv telesnih proporcev nogometašev in netrenirane populacije na prileganje hlač

Original scientific article/*Izvirni znanstveni članek*
Received/*Prispelo 4-2020* • Accepted/*Sprejeto 5-2020*

Corresponding author/*Korespondenčna avtorica:*
Blaženka Brlobašić Šajatović, PhD
E-mail: blazenka.brlobasic@ttf.hr
ORCID: 0000-0002-2252-0037

Abstract

The aim of this research was to identify the differences in body proportions between football players and the untrained population, and their influence on trouser fit. By identifying the differences in body measurements, and comparing the empirical and constructional values of body measurements required for the construction of men's trousers, an attempt was made to prove the need for a change in the existing cut of trousers. A total of 324 men aged 15 to 26 years participated in the research. The survey involved 162 football players with an average playing experience of 10.7 years and 162 untrained subjects from the general population. A total of 19 variables were analysed relating to the study of the fit of men's trousers. The SPSS software package was used for statistical data processing. The results showed that the football players were slightly but not significantly, taller, that their chest girth was almost the same as untrained subjects, and that their hip girth was slightly smaller. The greatest and most significant statistical difference was in the mid-thigh girth, which is greater in football players, and the waist girth, which is smaller in football players. Due to the identified value of a statistically significant increase of the mean thigh girth in football players, the modelling of trousers in this area was performed. The performed modelling of men's trousers met the criterion of garment fit, and opens the possibility of cooperation with industry in terms of improving the making of cuts for the surveyed sport population.
Keywords: body measurement, garment fit, clothing construction, football players, trousers

Izvleček

Cilj te raziskave je dokazati razlike v telesnih proporcih nogometašev in netrenirane populacije in njihov vpliv na prileganje hlač. Po ugotovitvi razlik v telesnih merah in primerjavi empiričnih in konstrukcijskih vrednosti telesnih mer, potrebnih za izdelavo moških hlač, je bila potrjena potreba po spremembi obstoječega kroja hlač. V raziskavi je sodelovalo 324 moških, starih od 15 do 26 let. Sodelovalo je 162 nogometašev s povprečnimi igralnimi izkušnjami 10,7 leta in 162 netreniranih oseb splošne populacije. Analiziranih je bilo 19 spremenljivk, pomembnih za proučevanje prileganja moških hlač. Podatki so bili statistično obdelani s programskim paketom SPSS. Rezultati so pokazali, da so bili nogometaši nekoliko višji, vendar ne bistveno, prsni obseg je bil skoraj enak kot pri netreniranih osebah, kolčni obseg pa nekoliko manjši. Največja in najpomembnejša statistična razlika je bila v obsegu sredine stegna, ki je bil pri nogometaših večji, in pasnem obsegu, ki je bil pri nogometaših manjši. Zaradi ugotovljene vrednosti statistično značilnega povečanja povprečnega obsega stegna pri nogometaših je bilo na tem

delu izvedeno modeliranje hlač. Modelirane moške hlače so ustrezale kriteriju pravilnega prileganja oblačila in s tem se odpira možnost za sodelovanje z industrijo v smislu izboljšanja krojev za anketirano športno populacijo.
Ključne besede: merjenje telesa, prileganje oblačila, konstrukcija oblačila, nogometaši, hlače

1 Introduction

People are increasingly interested in the fit and comfort of garments, but such garments are very difficult to find on the market. Garment cuts were made according to the standard. However, such clothing does not fit the entire population. In the trained population, there are deviations in some body measurements in relation to the standard system of clothing sizes, causing garments not to fit. In the production of fashion and sportswear, anthropometric measurements are applied in the field of design and modelling, and are obtained using anthropometric measurements on a sample of a given population [1]. By applying the conventional method using anthropometric instruments on the basis of the ISO 3635 (2008), ISO 8559 (2012) and ISO 9407 (2008) standards, the basics of a unique definition of human body measurements for the clothing and footwear industry were obtained, and for the implementation of anthropometric measurements (HRN EN 13402 (1–3) 2008) [2–3]. Proportions or relationships can establish the correct interrelationship between individual body parts or individual measurements.

Many authors are engaged in research on garment fit. The use of hand measurements is recommended to determine glove size so that the user can easily find the proper glove size [4]. The purpose of a sizing system is to fit the majority of a given population whose body proportions fall within predetermined standard dimensions. A sizing system can be defined as a method or system used to create a set of clothing for a variety of people on the target market [5]. Based on anthropometric measurements, the development of a new Chinese bra sizing system was based on anthropometric breast measurement. Factor analysis is often employed to determine key dimensions from the statistical aspect of anthropometric dimensions that are influential to major factors explaining the total sample variance, with a high percentage selected as key dimensions [6–8]. The authors Paal and McCulloch et al. [9, 10] proposed an optimisation approach to construct an apparel sizing system based on a mathematical model. They determined that the proposed method for establishing a sizing system could satisfy three aspects: 1. increase the accommodation of the population; 2. reduce the number of sizes in the system; and 3. improve overall fit in accommodated individuals. To obtain more comprehensive measurement variables, 3D body scanning is generally regarded as more complete. It would be ideal for measuring the entire population before defining the size range and body shape categorization of people. However, this is unrealistic in any sizing system development [11]. It is important to identify a representative sample of the population [12]. Based on the influence of sporting activities, there are changes in the morphological structure and relief surface of the body of persons who are actively involved in sports in relation to persons not active in sports. Through training, certain physical changes are achieved, which lead to changes in morphological structure, an increase in muscle mass and a decrease in fat tissue in certain body parts. With years of training, muscle mass can increase by between 30–60% [13]. Differences in body measurements and in body shape between basketball players and the untrained group of the general population of test subjects have been proven. Because of the shape differences, it is necessary to modify front and back block pattern parts, as well as the sleeves, in order to ensure additional ease allowance on increased areas and optimal garment fit [14]. According to research on the anthropometric characteristics of football players, other researchers obtained similar results with regard to body height, i.e. they concluded that the body height of football players does not differ significantly from the average height of the male population of the same age [15]. Differences were also found between the trained and untrained population, such as increased thigh circumference. Previous research on the anthropometric characteristics of football players relates to the study of anthropometric variables according to the instructions and regulations of the International Biological Programme (IBP). Anthropometric characteristics of the sport population have not been investigated from the aspect of the clothing industry. The aim of this research is anthropometric measurements of the sport population in accordance with the ISO 3635 and ISO 8559 standards, and the study of differences in relation to the untrained population and the impact of the identified effects on the fit of the trousers of football players.

2 Test subjects and research methods

A total of 324 men aged 15 to 26 years participated in the research. For the purposes of this research, the conventional method of anthropometric measurement was used to determine anthropometric sizes for young men (football players and the untrained population) in accordance with the ISO 3636 and ISO 8559 standards [8]. The survey involved 162 football players with an average playing experience of 10.7 years and 162 untrained subjects of the general population. The statistical analysis of the measured research variables was used to determine the main and design measurements for the two surveyed groups. Differences in body proportions between the two groups were defined. In order to meet the criteria of garment fit, the modelling of the front part of the trousers is shown for a group of football players (Figure 1).

The results of anthropometric measurements were processed using descriptive statistics, including an estimate of central tendency parameters (arithmetic mean and median) and dispersion (standard deviation, coefficient of variation, 95% confidence interval and data range). The correlation of individual body measurements and the suitability of standard procedures (mathematical expressions) for estimating body measurements depending on one and two predictors (basic body measurements) was verified using linear regression models with one and two predictors, respectively [16]. The modelling of computer body models for football players and the untrained population was carried out using the Optitex 3D software package, intended for construction preparation in the clothing industry. Body models were defined on the basis of the results of conventional anthropometric measurements, i.e. on the basis of average values of body measurements. Computer body models facilitated a clear visualisation of the bodies of the studied samples [1].

A total of 19 variables were studied: body height (1), chest girth (2), waist girth (3), hip girth (4), trouser length (5), crotch length (6), seat depth (7), waist height (8), hip height (9), knee height (10), ankle joint height (11), hip depth (12), total seat length (13), inside upper leg length (14), upper leg girth (15), middle leg girth (16), knee girth (17), girth under the knee (18) and lower leg girth (19). These are variables relating to the examination of the fit of men's trousers (Figure 2).

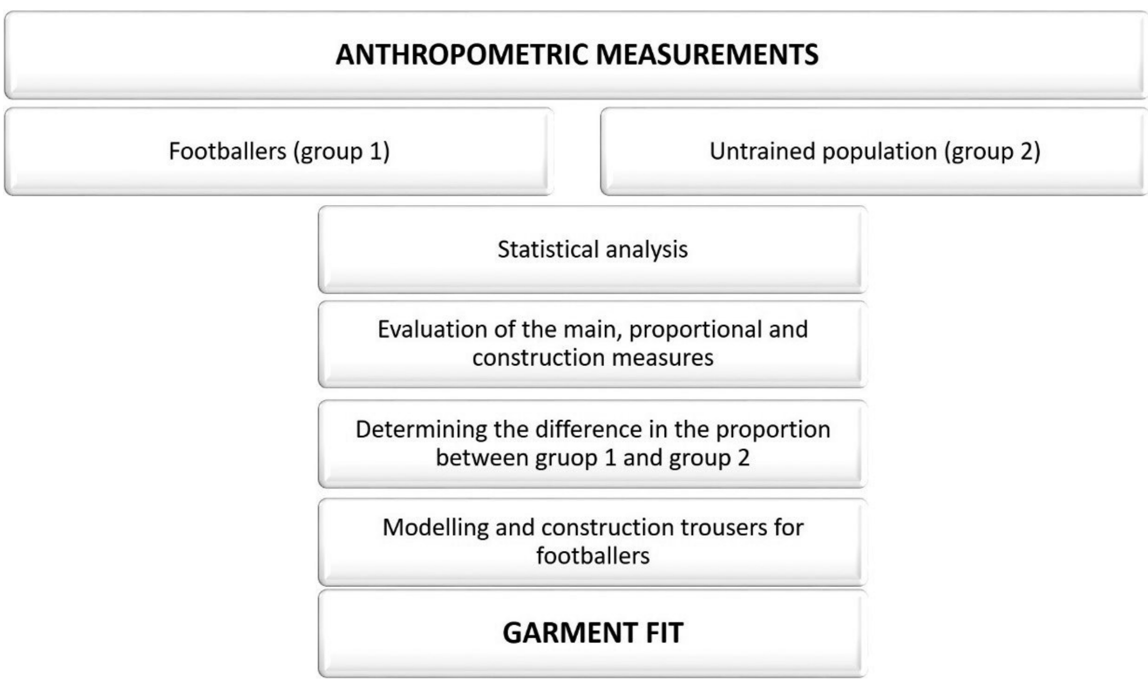


Figure 1: Research plan

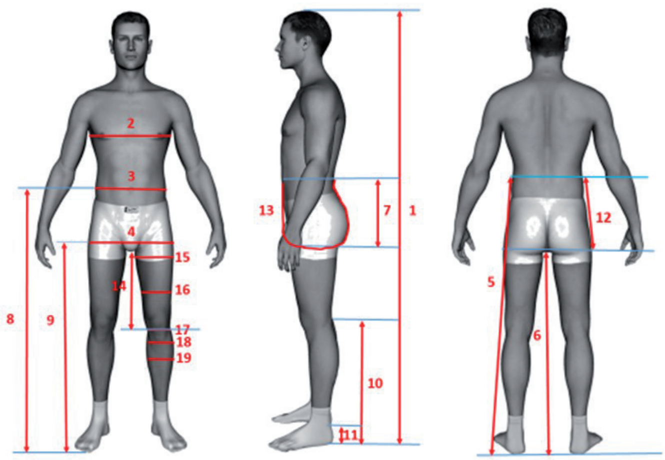


Figure 2: Researched variables

3 Results and discussion

The correlation of individual body measurements and the suitability of standard procedures (mathematical expressions) for estimating body measurements depending on a predictor were verified using linear regression models. The differences between the groups were tested using variance analysis.

Table 1 shows the indicators for the distribution of body measurements of football players and untrained groups of the general population measured using the traditional method of anthropometric measurement.

Table 1: Basic parameters of the distribution of body measurements of football players and untrained groups of the general population

Body measurements (cm)	Football players (cm)			Untrained populations (cm)			Differences	t	p
	X ± SD	Min	Max	X ± SD	Min	Max			
Body height	180.3 ± 5.64	166.5	193.0	179.4 ± 5.25	170.0	190.0	0.87	1.437	0.152
Chest girth	92.8 ± 5.42	81.0	108.0	92.7 ± 8.03	74.0	113.5	0.19	0.250	0.803
Waist girth	79.1 ± 6.11	68.0	104.0	81.5 ± 9.32	61.0	110.0	–2.46	–2.809	**0.005**
Hip girth	97.5 ± 4.94	84.0	112.0	98.3 ± 7.07	86.0	119.5	–0.78	–1.152	0.250
Trouser length	111.9 ± 5.84	90.0	125.0	110.0 ± 5.76	90.0	120.0	1.88	2.916	**0.004**
Crotch length	83.8 ± 4.31	72.5	98.5	83.1 ± 4.45	69.0	96.0	0.73	1.437	0.136
Seat depth	26.0 ± 4.42	17.0	35.0	25.3 ± 4.52	15.5	35.0	0.69	1.395	0.164
Waist height	110 ± 5.87	97.0	125.0	108.9 ± 4.98	96.0	119.0	1.01	1.677	0.094
Hip height	91.0 ± 4.55	79.5	102.5	90.5 ± 4.69	75.0	105.3	0.51	0.989	0.324
Knee height	52.2 ± 3.20	42.0	59.8	51.9 ± 3.69	42.2	63.0	0.38	0.987	0.324
Ankle joint height	5.1 ± 0.74	3.4	7.0	5.4 ± 0.85	3.5	7.5	–0.34	–3.835	**<0.001**
Hip depth	21.0 ± 1.87	17.0	26.0	20.9 ± 4.31	12.0	33.0	0.07	0.199	0.842
Total seat length	73.2 ± 6.76	57.0	92.0	72.7 ± 9.62	48.0	97.0	0.47	0.513	0.608
Inside upper leg length	33.6 ± 3.39	25.0	42.0	31.9 ± 4.14	18.5	42.0	1.70	4.049	**<0.001**
Upper leg girth	57.1 ± 3.86	47.0	69.0	55.0 ± 5.66	42.0	74.0	2.16	4.008	**<0.001**
Middle leg girth	52.1 ± 3.35	45.0	62.0	47.1 ± 5.51	45.0	62.0	5.02	9.910	**<0.001**
Knee girth	38.5 ± 2.0	34.0	46.0	38.3 ± 3.06	33.0	51.5	0.22	0.779	0.436
Girth under the knee	34.8 ± 2.07	30.0	43.0	34.9 ± 2.55	26.5	43.0	–0.04	–0.156	0.876
Lower leg girth	37.3 ± 2.66	28.0	44.0	36.7 ± 3.40	27.0	49.0	0.63	1.868	0.063

The results showed that the football players were slightly but not significantly taller, that their chest girth was almost the same as untrained subjects and that their hip girth was slightly smaller. The greatest and most significant statistical difference was in the middle leg girth, which is greater in footballers, and in the waist girth, which is smaller in football players. The scatter plots of pairs of the main body measurements of football players and the untrained group of the general population are shown in Figure 3 and confirm that these variables are linearly related to each other in both samples. According to the presented relations, there are no significant deviations between the main body measurements. These also do not result in changes in the construction of trousers. Figure 4 shows the empirical distribution of the statistically most significant differences in middle leg girth.

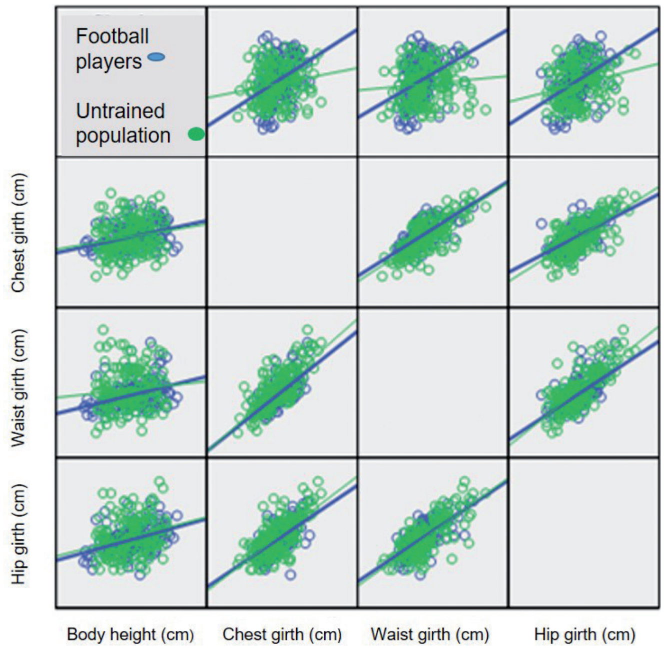


Figure 3: Scatter plots of height, chest, hip and waist girth of football players and the untrained group of the general population (N = 324)

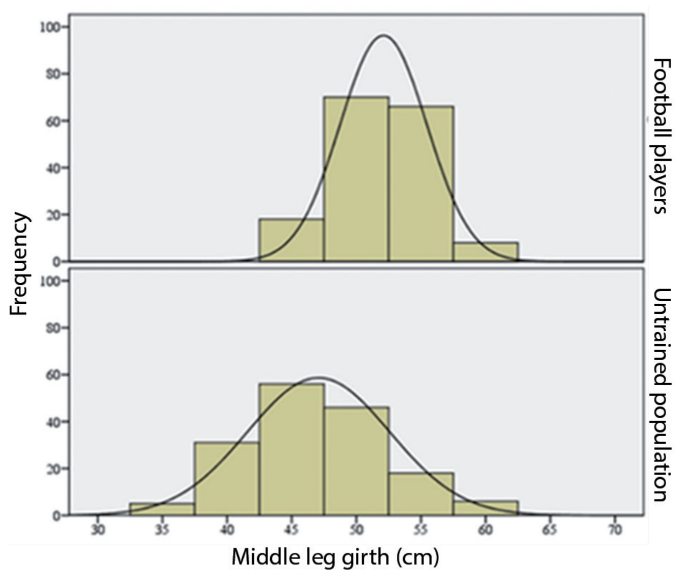
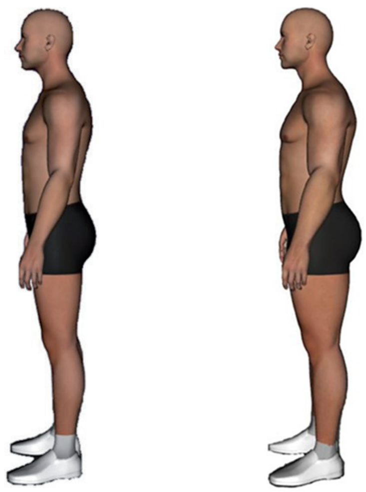


Figure 4: An empirical distribution of the statistically most significant differences in middle leg girth

On the basis of the results of statistical data processing, computer-aided 3D body models were created, separately for the group of football players and separately for the untrained group. Each 3D model shown was designed according to the mean values of body measurements. Figure 5 shows the body models of a football player and an untrained subject, showing their significant differences in body shape (e.g. in the middle leg girth, upper leg girth), which affect the cut of a football player's trousers.



a) b)

Figure 5: 3D computer body models created according to the mean values of body measurements: a) untrained population, b) football players

Table 2 presents the main, proportional and structural body measurements required for the construction of men's jeans. The main body measurements (body height, chest, waist and hip girth) were obtained on the basis of anthropometric measurements. The values of the main body measurements were used to calculate the construction measurements (trouser length, crotch length, seat depth, front trouser width, back trouser width, front seat width and back seat width). Mathematical expressions were used to calculate them. Based on the ratio between measured and calculated proportional body measurements (trouser length, crotch length and seat depth), the deviations of the body from the standard body shape were determined, and changes or adjustments to existing structures were necessary. The other previously mentioned proportional body measurements were difficult to measure accurately, so their values were determined solely based on mathematical formulas.

A constant of 40 cm was determined for measuring the circumference of the trouser leg [17].

Table 2: Main, proportional and structural body measurements for the construction of men's trousers

Variables	Construction measurements
Main body measurements	
Body height (Bh)	-
Chest girth (Cg)	-
Waist girth (Wg)	-
Hip girth (Hg)	-
Proportional and construction measurements	
Trouser length (Tl)	Tl = 5/8 Bh - from 4 to 5 cm
Crotch length (Cl)	Cl = ½ Bh – 4.5 cm
Seat depth (Sd)	Sd= Tl - Cl
Front width of trousers (Fwt)	Fwt = ¼ Hg
Back width of trousers (Bwt)	Bwt = ¼ Hg + from 2 to 3 cm
Front width of seat (Fws)	Fws = 1/20 Hg
Back width of seat (Bws)	Bws = 1/10 Hg + from 1 to 3 cm
Circumference of trouser leg	Ctl cca 40 cm

As shown in Table 3, the group of football players is different from the untrained group of subjects of the general population. The body measurements are described using arithmetic mean (), standard deviation (s), coefficient of variation (CV), reliability confidence interval (95%) and data range (minimum and maximum values) (Table 3).

Proportional and structural measurements vary equally for both groups of test persons and range between 3% and 7.2%, with the exception of the seat depth, which varies between 17% and 18% for both methods of determination (manual or computational) (Table 3).

Structurally, the trouser length was calculated as 5/8 of the body height minus 4 to 5 cm. Statistically, this ratio can be estimated by linear regression with body height as a predictor. Table 4 lists the parameters of such an assessment, showing that trouser length can be predicted based on body height ($p < 0,001$) and that this explains 37.3% of the variability in trouser length. The obtained regression coefficient with body height is 0.659 cm, which is almost indistinguishable from the construction coefficient 0.625, i.e. 5/8. The

Table 3: Descriptive statistical analysis and comparison of average body measurements obtained from football players and a control group of the general population for the construction of men's trousers

Proportional and construction body measurements/cm	Group	N a)	$\bar{x}$ b)	S c	CV d(%)	95% CI e		Range	
						h_1	h_2	Min.	Max.
Trouser length	Football	162	111.9	5.84	5.2	111.0	112.8	98.0	125.0
	Untrained	162	110.0	5.76	5.2	109.1	110.9	90.0	120.0
	Total	324	110.9	5.87	5.3	110.3	111.6	90.0	125.0
Trouser length (construction)	Football	162	108.2	3.53	3.3	107.6	108.7	99.6	116.1
	Untrained	162	107.6	3.28	3.0	107.1	108.1	101.8	114.3
	Total	324	107.9	3.41	3.2	107.5	108.3	99.6	116.1
Crotch length	Football	162	83.8	4.31	5.1	83.2	84.5	72.5	98.5
	Untrained	162	83.1	4.45	5.4	82.4	83.8	69.0	96.0
	Total	324	83.5	4.39	5.3	83.0	83.9	69.0	98.5
Crotch length (construction)	Football	162	85.6	2.82	3.3	85.2	86.1	78.8	92.0
	Untrained	162	85.2	2.62	3.1	84.8	85.6	80.5	90.5
	Total	324	85.4	2.73	3.2	85.1	85.7	78.8	92.0
Seat depth	Football	162	26.0	4.42	17.0	25.3	26.7	17.0	35.0
	Untrained	162	25.3	4.52	17.9	24.6	26.0	11.5	35.0
	Total	324	25.7	4.47	17.4	25.2	26.1	11.5	35.0
Seat depth (construction)	Football	162	28.1	5.14	18.3	27.3	28.9	8.5	40.0
	Untrained	162	26.9	4.98	18.5	26.1	27.7	10.0	42.9
	Total	324	27.5	5.09	18.5	26.9	28.0	8.5	42.9
Front width of trousers (construction)	Football	162	24.4	1.24	5.1	24.2	24.6	21.0	28.0
	Untrained	162	24.6	1.77	7.2	24.3	24.8	21.5	29.9
	Total	324	24.5	1.53	6.2	24.3	24.6	21.0	29.9
Back width of trousers (construction)	Football	162	26.9	1.24	4.6	26.7	27.1	23.5	30.5
	Untrained	162	27.1	1.77	6.5	26.8	27.3	24.0	32.4
	Total	324	27.0	1.53	5.7	26.8	27.1	23.5	32.4
Front width of seat (construction)	Football	162	4.9	0.25	5.1	4.8	4.9	4.2	5.6
	Untrained	162	4.9	0.35	7.2	4.9	5.0	4.3	6.0
	Total	324	4.9	0.31	6.2	4.9	4.9	4.2	6.0
Back width of trousers (construction)	Football	162	11.7	0.49	4.2	11.7	11.8	10.4	13.2
	Untrained	162	11.8	0.71	6.0	11.7	11.9	10.6	14.0
	Total	324	11.8	0.61	5.2	11.7	11.9	10.4	14.0
Circumference of trouser leg (construction)	Football	162	40.0	0.00	0.0	40.0	40.0	40.0	40.0
	Untrained	162	40.0	0.00	0.0	40.0	40.0	40.0	40.0
	Total	324	40.0	0.00	0.0	40.0	40.0	40.0	40.0

a) number of cases, b) arithmetic mean, c) standard deviation, d) coefficient of variation, e) reliability confidence interval (95%)

regression constant (-7.5 cm) exceeds the construction constant (-4.5 cm) by about 3 cm. However, it is not statistically significant, which means that it is adjustable as needed.

Structurally, the crotch length is determined as half of the body height reduced by 4.5 cm. Statistically, similar to the case of trouser length, this relationship can be estimated using linear regression with body height as a predictor. Table 4 lists the parameters of this estimate, showing that trouser length can be predicted based on body height ($p < 0,001$) and that 38.5% of crotch length variability was explained. The regression constant (-6.5 cm) exceeded the construction constant (-4.5 cm) by 2 cm, but was not statistically significant, i.e. it can be adjusted if necessary. Structurally, the seat depth was determined as trouser

Table 4: Estimate of trouser length (DHL) depending on body height (TV) using a linear regression model

Criterion	R^{2} a)	Predictor	Regression coefficient		
			B b)	β c)	p d)
Trouser length	37.3%	Constanta	–7.532		0.378
		Body height	0.659	0.612	**<0.001**
Crotch length	38.5%	Constanta	–6.470		0.306
		Body height	0.500	0.622	**<0.001**
Seat depth	16.2%	Constanta	15.858		**<0.001**
		Tl-Cl	0.357	0.406	**<0.001**

a) coefficient of determination, b) regression coefficient, c) standardized regression coefficient, d) significance of the regression coefficient

length minus the crotch length. The estimate of seat depth values using a linear regression model with this difference as a predictor did not yield results comparable to the design method. Table 4 lists the parameters of this estimate that show that seat depth can be predicted by the difference between empirical values of trouser length and crotch length ($p < 0,001$), but only explains 16.2% of the variability of empirical values of the criteria, i.e. seat depth. The obtained regression coefficient with a difference is 0.357 cm, while the regression constant is 15.9 cm and is a significant component of the regression model ($p < 0.001$). The empirical values determined for football players and the untrained group, as well as construction values, have no statistically significant influence on the construction of the trouser cut. However, due to the determined value of a statistically significant increase of the middle and upper thigh girth in football players, it is necessary to model the trousers in this area. In order to meet the criteria of the fit of the trousers as a garment, there are also very influential and additional body measurements, in addition to the construction and main body measurements. One of those measurements is mid-thigh girth.

Based on the analysis of body measurements and the determination of differences, Figure 6 shows the modelling of a pair of trousers for a group of football players to improve the trouser fit.

The modelling of trousers is based on previously conducted analyses and differences in body measurements between these two groups of subjects. The analysis of the measurement results showed that the mid-thigh girth was on average 5 cm larger than in the untrained group of test subjects, and the necessary redesign of the basic cut of men's trousers in this area was carried out accordingly.

The construction of trousers according to the standard (for the untrained population) is drawn in blue, and the modelling of trousers for football players is drawn in red. The trousers were modelled in the area of the mid-thigh girth in such a way that, on the line representing the middle of the front of the trousers from the hip depth to the knee height, widening was performed by 3 cm and the trousers were widened at the side seams by 1 cm on each side. The difference in the middle leg circumference is 5 cm, and for this reason the pants are widened by that amount.

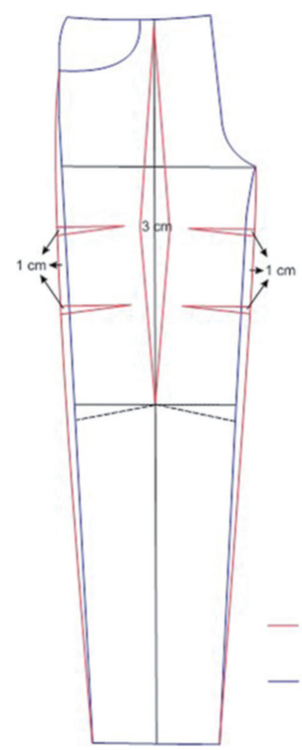


Figure 6: Modelling of the trouser cut in the area of the middle thigh girth of football players, - football players; - untrained populations

4 Conclusion

Differences in body proportions between the trained and the untrained group of test subjects were presented in this research. The largest statistically significant difference was found in the area of the mid-thigh girth. This variable has a significantly higher value among the surveyed football players and affects trouser fit. With this in mind, modelling and changes were made to the standard construction of the trouser cut to achieve a better fit. The garment fit criterion is defined by the parameters relating to the construction of the garment, which implies the correct joining of the garment in the sense that the garment has the appropriate size without being tightened anywhere on the body. The performed modelling of men's trousers met the criterion of garment fit, and opens the possibility of cooperation with the industry in terms of improving the making of cuts for the surveyed sport population.

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Timo Grothe, Jan Lukas Storck, Marius Dotter, Andrea Ehrmann
Bielefeld University of Applied Sciences, Faculty of Engineering and Mathematics, 33619 Bielefeld, Germany

Impact of Solid Content in the Electrospinning Solution on the Physical and Chemical Properties of Polyacrylonitrile (PAN) Nanofibrous Mats
Vpliv koncentracije elektropredilne raztopine na fizikalne in kemijske lastnosti polikrilonitrilnih (PAN) nanovlaknatih kopren

Short scientific article/*Kratki znanstveni prispevek*
Received/*Prispelo 06-2020* • Accepted/*Sprejeto 08-2020*

Corresponding author/*Korespondenčna avtorica:*
Prof. Dr. Dr. Andrea Ehrmann
E-mail: andrea.ehrmann@fh-bielefeld.de

Abstract
Polyacrylonitrile (PAN) belongs to the group of polymers that are often used for electrospinning, as it can be applied as a pre-cursor for carbon nanofibres and is spinnable from the low-toxic solvent dimethyl sulfoxide (DMSO). While the influence of different spinning parameters on fibre morphology and mass per unit area was investigated in a previous study, here we report on the impact of the spinning solution, using DMSO as a solvent and wire-based (needleless) electrospinning. Our results show that a broad range of solid contents can be applied, providing the opportunity to tailor the fibre diameter distribution or to optimize the areal weight of the nanofibrous mat by changing this parameter, while the chemical composition of the fibres remains identical.
Keywords: needleless electrospinning, polyacrylonitrile (PAN), nanofibrous mat, dimethyl sulfoxide (DMSO), Fourier-transform infrared (FTIR) spectroscopy

Povzetek
Poliakrilonitril (PAN) spada med polimere, ki se pogosto uporabljajo za elektropredenje, saj ga lahko namenjajo za prekurzor ogljikovih nanovlaken in ker ga je mogoče presti iz nizkotoksičnega topila dimetil sulfoksida (DMSO). Medtem ko je bil vpliv različnih parametrov predenja na morfologijo vlaken in ploščinsko maso raziskan v prejšnji študiji, tukaj poročamo o vplivu predilne raztopine na osnovi topila DMSO in brezigelnega postopka elektropredenja. Naši rezultati kažejo, da je z uporabo širokega območja trdne snovi mogoče prilagajati porazdelitev premera vlaken ali optimizirati ploščinsko maso nanovlaknate koprene, medtem ko ostaja kemična sestava vlaken enaka.
Ključne besede: brezigelno elektropredenje, poliakrilonitril (PAN), nanovlaknata koprena, dimetil sulfoksid (DMSO), Fourierjeva infrardeča spektroskopija s Fourierjevo transformacijo (FTIR)

1 Introduction

Electrospinning is a simple method used to prepare nanofibrous mats with fibre diameters in a typical range of several ten nanometres to a few micrometres [1, 2]. While many research groups apply a needle-based technique [3–5], needleless technologies are often easier to upscale to industrial production [6–8]. In such needleless techniques, a wire, a rotating cylinder or other free surfaces can be used as electrodes. In all technologies, a strong electric field concentrates electric charges along the polymer surface, resulting in the formation of so-called Taylor cones, and finally pulls drops of solution towards the counter electrode [9, 10]. During this movement, the drop is severely stretched and thus forms a thin fibre when impinging on the substrate. From this description, it is already clear that not only spinning parameters – such as the voltage and the distance between the electrodes – influence the fibre formation process, but also environmental parameters, in particular the humidity in the spinning chamber, and finally the spinning solution itself [11–14].

An electrospinning technique facilitates the creation of nanofibres from a broad range of polymers and polymer blends [15–17], as well as combinations with non-polymeric materials [18–20]. Polyacrylonitrile (PAN) belongs to a group of highly interesting polymers, as it can be electrospun from the low-toxic solvent dimethyl sulfoxide (DMSO) and is often used as a precursor for carbon nanofibres [14, 19].

Such nanofibre mats can be used in a variety of applications, such as filters [21–23], tissue engineering and cell growth [24–26], catalysers [27, 28] and other technologies that are usually based on a large surface-to-volume ratio. For this reason, it is often important to tailor fibre diameters and possibly even fibre orientations according to the experimental necessities [29–31].

While the influence of the spinning parameters on fibre morphology and areal weight of PAN nanofibres produced using wire-based electrospinning was investigated in a previous study [32], here we report on the influence of the polymer content in the spinning solution on nanofibre diameter distribution, mass per unit area and the chemical composition of the resulting nanofibrous mat. In combination with the previous study, our findings facilitate the tailoring of these physical parameters by optimizing spinning and solution parameters.

2 Materials and methods

Samples were prepared using a "Nanospider Lab" needleless electrospinning machine (Elmarco Ltd., Liberec, Czech Republic). The spinning parameters were: voltage of 75 kV, nozzle diameter of 0.8 mm, carriage speed of 100 mm/s, distance from bottom electrode to substrate of 240 mm, distance from ground electrode to substrate of 50 mm, temperature in the chamber of 21–22 °C, relative humidity in the chamber of 33%, and a spinning duration of 10 minutes. The substrate is a static polypropylene nonwoven fabric, enabling a comparison of the areal weights of the electrospun nanofibrous mats with solid contents of the spinning solutions.

Spinning solutions were prepared with 12–22% PAN dissolved in DMSO (min. 99.9%; S3 Chemicals, Bad Oeynhausen, Germany). All percentages of PAN concentration given here refer to weight percentage. Lower solid contents (10% or less) resulted in pure electro-spraying without fibre formation, while higher solid contents (24% or more) were no longer spinnable. For lower solid contents (12–14% in the case of relative humidity of just 31–32% in the spinning chamber and 16% in the case of relative humidity of 33–34%), beads can be expected to form during electrospinning [14]. It should be mentioned that these values differ significantly from those that can be applied in the needle-based electrospinning of PAN, for which Wang *et al.* found values from 4% to 10% to be spinnable from the solvent dimethylformamide (DMF) [33].

Images of the nanofibrous mats were taken with a VK-8710 confocal laser scanning microscope (CLSM) (Keyence, Neu-Isenburg, Germany). Fibre diameters were evaluated using ImageJ 1.51j8 (National Institutes of Health, Bethesda, MD, USA), while fast Fourier transform (FFT) evaluations were performed using the same software. Such FFT images can be used to identify fibre alignment, which becomes visible as single lines in certain directions [31, 34].

Chemical investigations were performed using an Excalibur 3100 Fourier transform infrared (FTIR) spectrometer (Varian Inc., USA). Solution viscosities were measured using a Brookfield Viscometer DV-II+ Pro dynamic viscometer. An LWT-01 conductivity test pen (Voltcraft) with a resolution of 10 µS/cm was used for conductivity measurements of the spinning solutions.

3 Results and discussion

The morphologies of the nanofibrous mats under investigation are depicted in Figure 1. For the three lowest solid contents (12%, 14%, and 16%), the images look very similar, showing a relatively regular nanofibre mat with some thick, long fibres on top that do not seem to be fully connected with the main part of the mat. Interestingly, under the environmental conditions used here, there is no strong bead formation visible.

However, increasing the solid content to 18% clearly changes the morphology of the nanofibrous mat. Here, relatively long, thick and straight fibres are visible, apparently less connected and with larger pores than in the main part of the previously described samples. Such clearly visible fibres can also be derived by reducing the voltage to approximately 55–65 kV for a solid content of 14–16%, as previous experiments showed, but at the cost of a reduced areal weight [32].

Increasing the solid content further to 20% unexpectedly resulted in even thicker fibres with strong conglutinations. Such a highly connected net could, for example, be useful for data transport through magnetic nanofibres [19] or in applications in which mechanical stability is essential, while the large pores and the reduced surface-to-volume ratio can be neglected.

Finally, for the highest solid content in the solution, it is obvious that only a few fibres are electrospun from

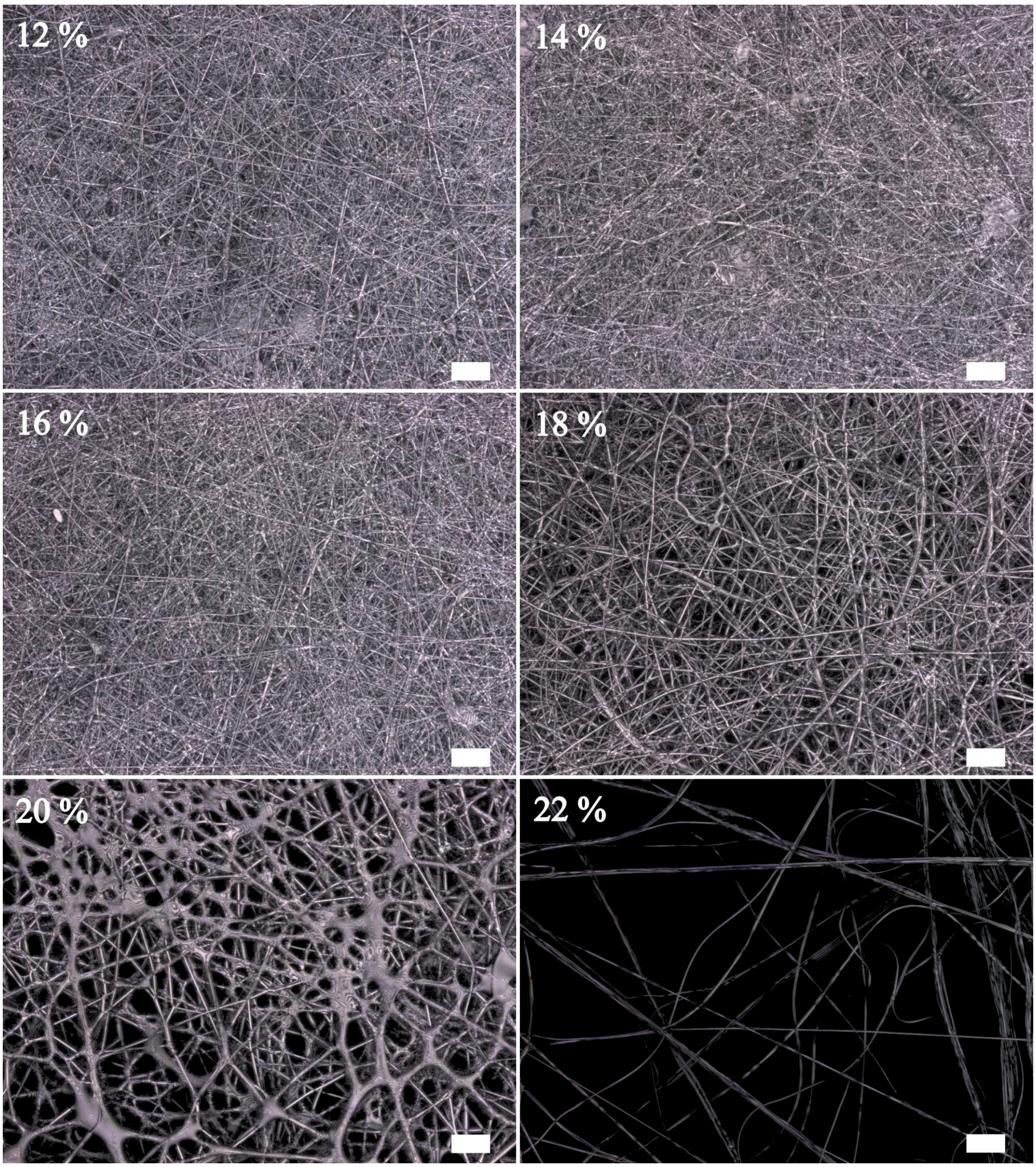

Figure 1: Representative CLSM images of PAN nanofibre mats, electrospun with identical spinning parameters from DMSO solutions with varying solid content. Scale bars indicate 10 μm.

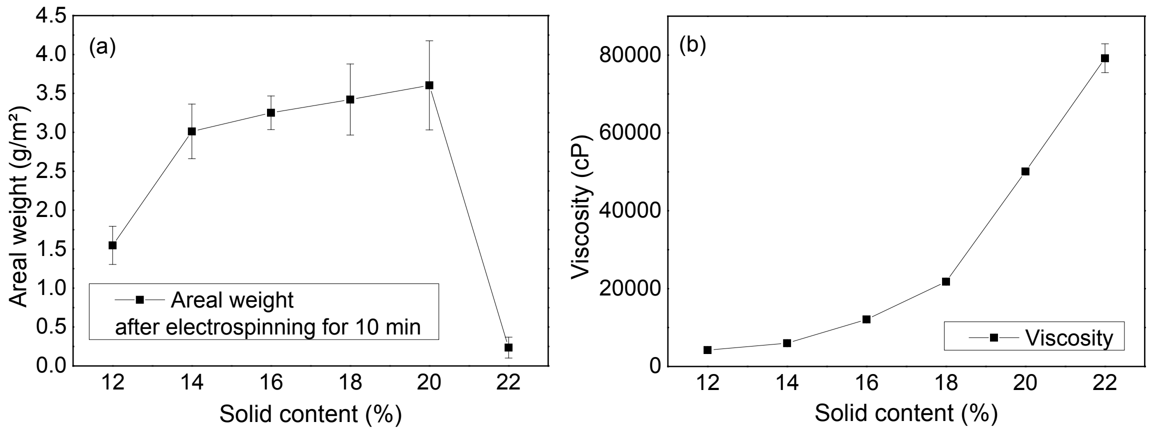

Figure 2: (a) Solid content dependence of the areal weight of the PAN nanofibrous mats under investigation; (b) dynamic viscosity of the corresponding spinning solutions

the solution with 22% PAN. This could also be observed during the spinning process where nearly no flying fibres were observed in the spinning chamber. It should be mentioned that additional FFT investigations (not shown here) supported the optical impression that the fibres do not show any angular orientation, corresponding to the expectation for a nanofibre mat electrospun on a static, fully non-conductive substrate.

Next, Figure 2a depicts the dependence of the areal weight on the solid content of the spinning solutions. While the curve increases sharply from 12% to 14% and almost linearly until 20%, it drops suddenly towards a solid content of 22%, as could already be expected from Figure 1. This is due to an increase in viscosity that exceeds the spinnability limit for the needleless spinning technique and no longer flows through the spinning nozzle properly. Viscosity values are given in Figure 2b for comparison. It should be mentioned that solutions with solid contents of 12–20% behaved nearly fully Newtonian in the measured range of rotational speeds, which is why the error bars are too small to be visible. Only for the spinning solution with 22% PAN, is a slight increase of the dynamic viscosity with increasing rotational speed visible, i.e. the fluid becomes shear-thickening. Combining both figures suggests that a solid content of 16–18% should be ideal for the wire-based electrospinning of PAN from DMSO, thus giving relatively high material yields while still allowing for the modification of the nanofibre diameter distribution. It should be mentioned that the conductivity of the solutions was in the range of 30–50 μS/cm for all solutions, well below the maximum suggested conductivity of 10 mS/cm for the Nanospider, and thus can be expected to have no influence on the results of the spinning process.

The nanofibre diameter distribution is depicted in more detail in Figure 3. For the lower concentrations of 12–16%, only a slight increase of the nanofibre diameter distribution is visible, with similar standard deviations, i.e. similar distribution widths. For a PAN content of 18%, as could already be seen in Figure 1, the diameter distribution is significantly shifted, while at the same time the standard deviation increases. Some fibres with larger diameters of around 750–1000 nm indicate that this PAN concentration is near to or slightly above the threshold below which a reliable fibre diameter distribution can be reached. This finding suggests further tests with solid contents of 17.0–17.5%, which could possibly lead to a compromise between the clearly differentiated, long, straight fibres prepared with an 18% PAN concentration and the narrower diameter distribution achieved with smaller concentrations.

Finally, for concentrations of 20% and 22%, the distributions become very broad, with large standard deviations that are unacceptable for many applications, clearly showing that the highest areal weight, achieved with a concentration of 20%, comes at the cost of an undefined morphology of the nanofibrous mat.

The chemical composition of the nanofibre mats under investigation can be derived from the FTIR graphs in Figure 4. The typical PAN peaks represent the bending and stretching vibrations of CH_2 at 2938 cm^{-1}, 1452 cm^{-1} and 1380 cm^{-1}, stretching vibrations of the C≡N nitrile functional group at 2240 cm^{-1}, and the carbonyl (C=O) stretching peak at 1732 cm^{-1} [35].

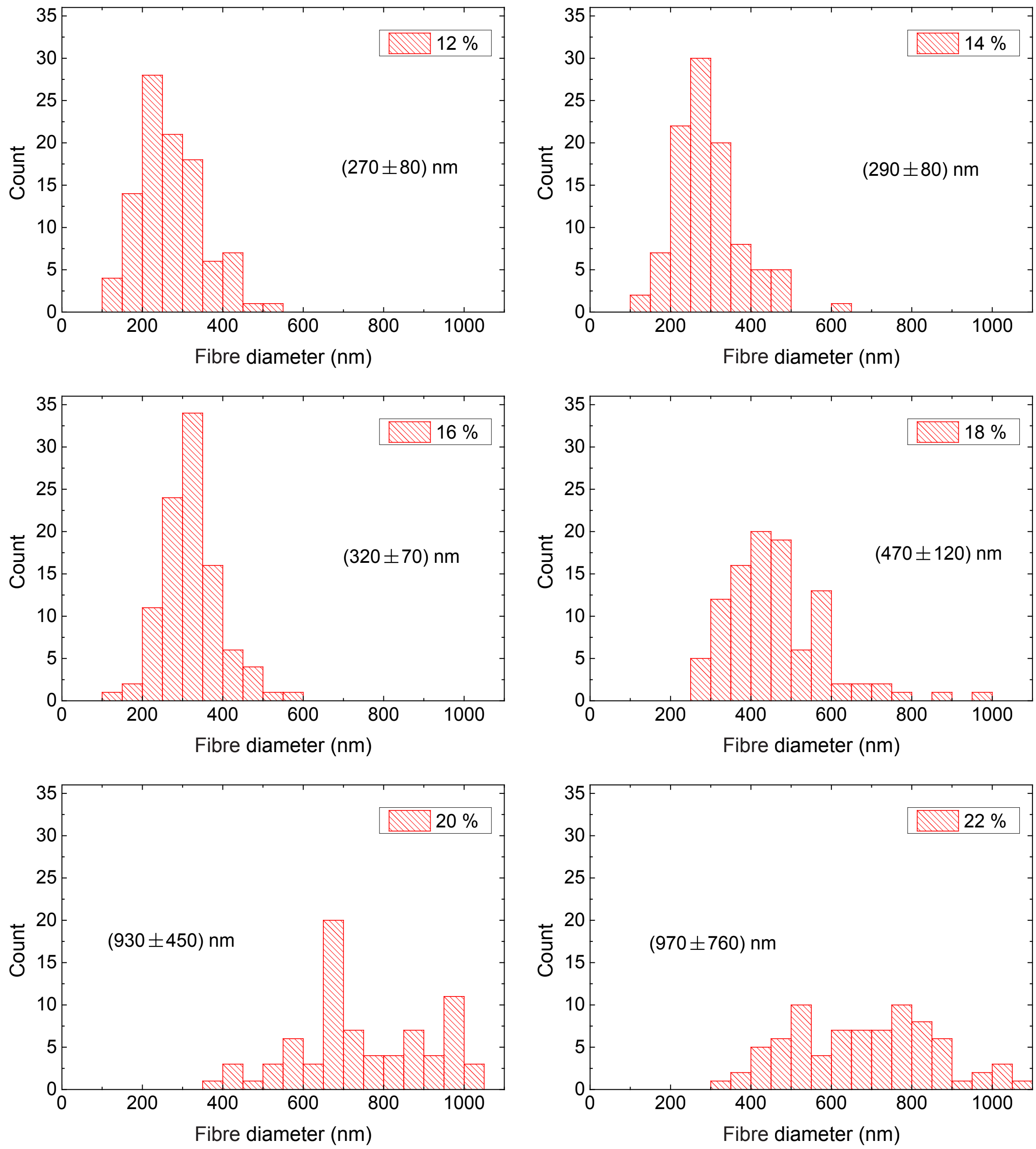

Figure 3: Fibre diameter distributions of nanofibrous mats, electrospun from solutions with different solid contents, for 100 fibres each. Insets show averages ± standard deviations

The peaks not marked here in the ranges of 1250–1230 cm^{-1} and 1090–1030 cm^{-1} belong to C–O and C–O–C (ester) vibrations of co-monomers, such as itaconic acid or methyl acrylate, which are often added to PAN [35]. Around 2360–2320 cm^{-1}, double-peaks are visible, which can sometimes be observed in FTIR measurements and are usually based on CO_2 in gaseous and aqueous form [36], i.e. an artefact.

Besides these undesired effects, all PAN peaks look identical in all samples, which could be expected as the composition of the solid content of the spinning solutions remained unaltered. Small deviations between the heights of the peaks can be attributed to thickness deviations and air inclusion in the thin nanofibre mats, in this way varying the overall signal. This shows that the chemical composition of the PAN nanofibre mats remains unaltered when the solid content in the solution is varied.

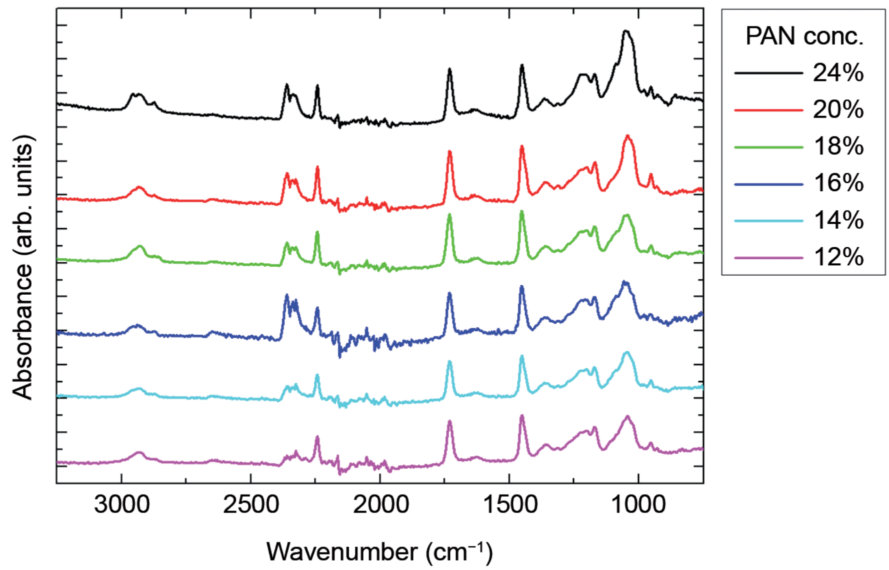

Figure 4: FTIR (Fourier transform infrared spectroscopy) graphs of nanofibrous mats, electrospun with different PAN concentrations, given in weight percentage

4 Conclusion and outlook

Needleless electrospinning of PAN from DMSO can be performed for a broad range of solid contents in the solution. Our investigations reveal that concentrations of between 14% and 18% are ideal for most applications, resulting in high material yields and narrow fibre diameter distributions, while facilitating the tailoring of the diameter to a certain extent. Higher concentrations of 20% result unexpectedly in conglutinated fibres, which may be interesting for certain applications in which mechanical strength is more important than the high surface-to-volume ratio of the nanofibrous mats produced at lower concentrations. A solid content of 22% is no longer spinnable, while a PAN concentration of 12% also resulted in a low material yield. For all samples under examination, the chemical composition remained unaltered.

Our study facilitates the identification of the optimum PAN concentrations for wire-based electrospinning, which are quite different from the optimal values for the needle-based technique.

Because PAN nanofibrous mats are often used as a precursor for carbon nanofibres, future investigations are necessary to examine the influence of the PAN concentration on the morphology and mechanical properties of carbonized nanofibrous mats, and on the carbon yield.

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Snezhina Angelova Andonova
Faculty of Engineering, South-West University "Neofit Rilski", 66 Ivan Mihailov Str., 2700 Blagoevgrad, Bulgaria

Influence of Fusing Conditions on the Change of Colour Shade in the Production of Clothing

Vpliv pogojev fiksiranja na spremembo barvnega odtenka pri proizvodnji oblačil

Original scientific article/*Izvirni znanstveni članek*
Received/*Prispelo 5-2020* • Accepted/*Sprejeto 8-2020*

Corresponding author/Korespondenčna avtorica:
Assoc. Prof. Eng. Snezhina Andonova, PhD
E-mail: andonova_sn@abv.bg
ORCID: 0000-0003-0818-9947

Abstract
One of the major technological processes in the sewing industry is the process of thermo-mechanical fusing (TMF). This is a process in which the main textile material connects to an additional textile material (interlining) through a polymer binder. This ensures better resistance to the shape of the individual parts of the sewing article. The main factors that influence the process are the temperature of the pressing plates, and the pressure and the duration of the process. The process has not been sufficiently studied and therefore it is important to identify a function that connects the output parameter to the input factors of the TMF process. It is especially important to choose an optimisation criterion. After numerous preliminary studies, some changes in textile materials (TM) after TMF have been observed. For example, the incorrect adjustment of process parameters (e.g. pressure, temperature and duration) changes the colour shade of TM after TMF. This change in the colour shade of the individual parts will impair the quality of the sewing product as a whole. This encourages the selection of the quality criterion. In light of the latter, the purpose of this paper was to derive a mathematical model of the TMF process that describes the influence of input factors on the quality criterion: changing the colour shade of TM after TMF.
Keywords: thermo-mechanical fusing process, change of colour shade

Izvleček
Eden glavnih tehnoloških procesov v konfekcijski industriji je termomehanski postopek fiksiranja. To je postopek, pri katerem se osnovni tekstilni material poveže z dodatnim tekstilnim materialom (medvlogo) s polimernim lepilnim termoplastom. S tem se poveča obstojnost oblike posameznih delov šivanega izdelka. Glavni dejavniki, ki vplivajo na postopek, so temperatura stiskalnih plošč, tlak in časovni potek postopka. Sam postopek fiksiranja še ni bil v celoti raziskan z vidika funkcijske odvisnosti med vhodnimi dejavniki termomehanskega taljenja z izhodnimi parametri. Še zlasti je pomembna možnost izbire optimalnih kriterijev. Po številnih predhodnih študijah so bile opažene nekatere spremembe tekstilnih materialov po termomehanskem taljenju. Na primer, nepravilna nastavitev parametrov (tlaka, temperature in časa) spremeni barvni odtenek tekstilnega materiala po fiksiranju. Takšna sprememba barvnega odtenka posameznih oblačilnih delov poslabša kakovost oblačila kot celote. To narekuje pravilno izbiro kriterijev kakovosti, zato je v članku izpeljan matematični model termomehanskega fiksiranja, ki opisuje vpliv vhodnih dejavnikov na enega od kriterijev kakovosti – spreminjanje barvnega odtenka tekstilnega materiala končnega izdelka.
Ključne besede: termomehanski postopek fiksiranja, sprememba barvnega odtenka

1 Introduction

One of the major technological processes in the sewing industry is the process of thermo-mechanical fusing (TMF). This is a process in which the main textile material connects to an additional textile material (interlining) through a polymer binder. This ensures better resistance to the shape of the individual parts of the sewing article. The main factors that influence the process are the temperature of the pressing plates, and the pressure and the duration of the process. From the study conducted, it can be summarised that some investigations were made to determine the effect of individual parameters on the TMF process [1–4]. However, the combined influence of controllable factors, for example to satisfy the quality and performance criteria, has not been sufficiently studied.

Globally, many elite companies have conducted research in this area, but their studies are commercial or confidential. In this context, it is necessary to derive a mathematical model of the TMF process through research and analysis with the help of modern control and measuring equipment. It is especially important to choose an optimisation criterion.

Optimisation criteria (i.e. output parameters) can be quality criteria or performance criteria. In industrial technology, time is often used as a criterion for productivity [5–8]. In one study [9], a mathematical model of the TMF process was created to describe the relationship between the duration of the process and input factors. In any scientific study, it is especially important to define an effective quality criterion, as well. Quality assurance and quality control represent a complex area of the apparel industry. Quality assurance is not quality control, but quality control is an aspect of quality assurance. Quality assurance builds quality into each step of the manufacturing process [10]. Therefore, it is especially important to study the influence of TMF conditions on the quality of the sewing product [11]. From the literature review, it can be concluded that this issue has not been sufficiently investigated. After numerous preliminary studies, some changes in textile materials (TM) after TMF have been observed. For example, the incorrect adjustment of process parameters (e.g. pressure and temperature) changes the colour shade of TM after TMF. For some technological processes, colour change is a desired effect. It is especially fashionable to generate faded effects on indigo dyed denim fabric [12]. For the TMF technological process, however, the change of the colour shade of the main textile materials is an entirely undesirable effect.

The change in the colour shade of individual parts will impair the quality of the sewing product as a whole. This encourages the selection of the quality criterion. In this work, the colour change after TMF is used as a quality criterion. The conditions for carrying out the TMF process are also especially important. In recent years, the sewing industry has used an increasing number of new and different textile materials. Each of them has a different composition and structure. It is rare to find two fibres or textile materials at random that exhibit the same characteristics [13]. This determines their different properties [5, 9, 14, 15]. In light of the latter, it is important to choose a manageable factor that is related to the type and structure of the studied textile materials. One study [16] illustrates the relationship between the mass per unit area, the composition and the structure of the respective type of textile material.

The purpose of this paper was to derive a mathematical model of the TMF process that describes the influence of the input factors (e.g. pressure, the temperature of the pressing plates and the mass per unit area of basic textile materials) on the quality criterion: changing the colour shade of TM after TMF.

2 Experimental work

When carrying out experimental work it is important to take into account the reflective properties of the TM. These properties depend on many factors. They include colour, dye concentration, composition and structure of TM and many others. For this reason, TMs of the same colour are used in the experiment. On the other hand, this ensures the reproducibility of the process.

2.1 Methods

In formulating the conditions and methods for conducting the experiment, the principles of the morphological method for analysis and synthesis of methods were applied [17]. It is important to determine the method for quantifying the change in colour shade of TM after TMF. This quantification in the present work was carried out using a modern objective method. The DATA COLOR measurement system was used for colour measurement. That system comprises a spectrophotometer and a computer.

The device used was highly sensitive. The method was carried out over a short time frame, with a sufficient degree of accuracy. It is reproducible, versatile and affordable. The studies were performed with monochromatic TMs, coloured in black.

The full factorial experiment (FFE) method was used to create a mathematical model. It implements all possible combinations of two levels of factors. The number of these combinations for n factors is N = 2n [5, 18].

The basic elements for the compilation of the mathematical model were determined using the methodology for the implementation of FFE [5, 18].

2.2 Conditions for conducting the experiment

In order to determine the conditions for conducting the experiment, it was also necessary to select manageable factors.

The following were selected for controllable (manageable) factors: X_1 representing the pressure of the pressing plate, P (N/cm^2); X_2 representing the temperature of the pressing plates, T (°C); and X_3 representing the mass per unit area of basic textile materials, M (g/m^2). The main factor levels and intervals of variation are given in Table 1 [9].

The temperature between the basic TM and the auxiliary TM (interlining) was T_M (material temperature). After conducting a number of preliminary studies, the following conditions for conducting the experiments were selected:

- an ATLAS - I. BALA - 4-93 fusing machine (stationary press type "drawer"); and
- the TM temperature (T_M) was recorded with a computer integrated measurement system [19].

The temperature (T_Q) is assumed to be the temperature required for quality bonding when working with the textile materials described.

The fusing process was finalised when T_M reached T_Q [4].

After numerous preliminary experiments, it was found that T_Q = 112 °C for the studied T_M.

2.3 Materials

Materials produced by the company NITEX-50 (Sofia) were used for basic textile materials.

They were 100% wool fabrics: article EKSELSIOR with a mass per unit area 173 g/m^2, warp threads density of 122 pcs/10 cm and weft threads density of 230 pcs/10 cm; article RITZ with a mass per unit area of 193 g/m^2, warp threads density of 175 pcs/10 cm and weft threads density of 263 pcs/10 cm; and article KARDINAL with a mass per unit area 213 g/m^2, warp threads density of 370 pcs/10 cm and weft threads density of 232 pcs/10 cm [9].

Material produced by the company Kufner-B121N77 was used for interlining textile material (auxiliary textile material). The interlining TM is tissue with a mass per unit area of 63 g/m^2, warp threads of 100% PES and weft threads of 100% PES.

3 Results and discussions

3.1 Experimental results

The design of the experiment is given in Table 2.

The number of factor levels is k = 2; the number of factors is n = 3 (I, l and p representing the sequences numbers of factors), therefore [5, 18] N = 8.

3.2 Discussion of experimental results

It is necessary to carry out a process reproducibility check, which is reduced [5, 18] to a variance perseverance check (using Cochran's C test).

The results for the calculated and tabulated value of the Cochran's C test are:

$$G_C = \frac{S^2_{j\max}}{\sum_{j=1}^{N} S_j^2} = 0{,}125 \tag{1}$$

$$G_T\{f_1 = m - 1; f_2 = n; r = 0{,}05\} = 0{,}6798 \tag{2}$$

where: "r" represents the significance level and "f_1" and "f_2" represent degrees of freedom.

Table 1: Factor levels

Factors levels	X_1 – P (N/cm^2)		X_2 – T (°C)		X_3 – M (g/m^2)	
	Natural	Coded	Natural	Coded	Natural	Coded
$X_{oi} + J_i$	40	+ 1	150	+ 1	213	+ 1
X_{oi}	25	0	135	0	193	0
$X_{oi} - J_i$	10	– 1	120	– 1	173	– 1
J_i	15		15		20	

Table 2: Design of the experiment

№	X_0	X_1	X_2	X_3	X_1X_2	X_1X_3	X_2X_3	$X_1X_2X_3$	$\overline{Y}_J$	Y_{jC}
1	+	–	–	–	+	+	+	–	0.5	0.4925
2	+	+	–	–	–	–	+	+	1.2	1.2075
3	+	–	+	–	–	+	–	+	1.07	1.0625
4	+	+	+	–	+	–	–	–	1.63	1.6375
5	+	–	–	+	+	–	–	+	0.91	0.9175
6	+	+	–	+	–	+	–	–	1.57	1.5625
7	+	–	+	+	–	–	+	–	1.25	1.2575
8	+	+	+	+	+	+	+	+	1.91	1.9025

The number of repetitions of the jth test (j = 1÷N) is m = 2.
The results of the experiments ($\overline{Y}_J$) are also given in Table 2.

Therefore, the intra-group variance does not differ statistically and the process is reproducible.
Regression coefficients were determined using formulas (3) to (12) [5, 18]:

$$b_o = \frac{1}{N}\sum_{j=1}^{N}\overline{Y}_j = 1{,}255 \quad (3)$$

$$b_i = \frac{1}{N}\sum_{j=1}^{N}x_{ij}\overline{Y}_j \quad (4)$$

$$b_1 = 0{,}3225 \quad (5)$$

$$b_2 = 0{,}21 \quad (6)$$

$$b_3 = 0{,}155 \quad (7)$$

$$b_{il} = \frac{1}{N}\sum_{j=1}^{N}x_{ij}x_{lj}\overline{Y}_j \quad (8)$$

$$b_{12} = \frac{1}{N}\sum_{j=1}^{N}x_{1j}x_{2j}\overline{Y}_j = (-0{,}0175 \quad (9)$$

$$b_{13} = 0{,}0075 \quad (10)$$

$$b_{23} = (-0{,}04) \quad (11)$$

$$b_{ilp} = b_{123} = \frac{1}{N}\sum_{j=1}^{N}x_{1j}x_{2j}x_{3j}\overline{Y}_j = 0{,}0175 \quad (12)$$

The output parameter variance was defined according to (13) [5, 18]:

$$S_j^2(Y) = \frac{1}{m-1}\sum_{u=1}^{m}(Y_{ju} - \overline{Y}_j)^2 \quad (13)$$

The variance of reproducibility was determined according to (14) [5, 18]:

$$S_R^2 = \frac{1}{N}\sum_{j=1}^{N}S_j^2(Y) = 0{,}0002 \quad (14)$$

The variances of the regression coefficients were determined according to (15) [5, 18]:

$$S_{(Bi)}^2 = \frac{S_{(Y)}^2}{N(m-1)} = 0{,}000025 \quad (15)$$

The significance of the calculated regression coefficients was verified. Student's t-test was used. Only those coefficients were significant for which the following was valid [5, 18]:

$$t_C > t_T, \quad (16)$$

where: t_C represents the calculated coefficient; t_T represents the table value of Student's t-test, with the selected significance level of r = 0,05 and the degree of freedom of f = N (m–1) = 8.
The value of Student's t-distribution was defined as: $t_T = 2.31$.
t_C was determined according to (17) [5, 18]:

$$t_C = \frac{|B_i|}{S_{(B_i)}} \quad (17)$$

Therefore: $t_{C(b0)} = 251$; $t_{C(b1)} = 64.5$; $t_{C(b2)} = 42$; $t_{C(b3)} = 31$; $t_{C(b12)} = 3.5$; $t_{C(b13)} = 1.5$; $t_{C(b23)} = 8$; $t_{C(b123)} = 3.5$.

The only insignificant coefficient was b_{13}, the absolute value of which was smaller than the critical value. After eliminating the insignificant coefficient, the model took the following form:

$$Y_C = 1{,}255 + 0{,}3225 \cdot x_1 + 0{,}21 \cdot x_2 + 0{,}155 \cdot x_3 - 0{,}0175 \cdot x_1 \cdot x_2 - 0{,}04 \cdot x_2 \cdot x_3 + 0{,}0175 \cdot x_1 \cdot x_2 \cdot x_3 \quad (18)$$

Verification of model adequacy:

- the adequacy variance was established (19) [5, 18]:

$$S^2_{ad.} = \frac{m}{f} \sum_{j=1}^{N} (\overline{Y}_j - \overline{Y}_{jC})^2 = 0{,}0009 \quad (19)$$

where: f = N–M=1, Y_{jC} represents the value calculated by the mathematical model (Table 2) and M represents the number of significant regression coefficients.

- the expected Fisher's F-test was calculated according to (20) [18]:

$$F_C = \frac{S^2_{ad.}}{S^2_{(Y)}} = 4{,}5 \quad (20)$$

- the table value of Fisher's distribution was:

F_T {r = 0.05; f_1 = N–M = 1; f_2 = N(m-1) = 8} = = 5.32 [5, 18].

As $F_C = 4.5 < 5.32 = F_T$, the model is adequate [5, 18]. Therefore, the hypothesis that a mathematical model of the type (18) is adequate can be accepted with a confidence probability of P = 0.95.

4 Conclusion

After a thorough analysis of the nature and characteristics of the technological TMF process of a stationary press type "drawer", a full factorial experiment was planned to make a mathematical model of the process. The change in the colour shade of the sewing parts after TMF was selected as a quality criterion. A mathematical model of the TMF process was created for the corresponding experimental conditions. It showed how the output quality parameter is linked to the input factors, i.e. the pressure P (N/cm^2), temperature T (°C) and mass per unit area of basic textile materials M (g/m^2).

The conducted research has an applied-scientific character. The mathematical model obtained creates the conditions for quickly finding another combination of inputs that satisfies the quality criterion. This helps to quickly solve real production problems and optimise the process.

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