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Fabrication of Compressed Hosiery and Measurement of its Pressure Characteristic Exerted on the Lower Limbs

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Dear, Dr. Werth

I enclose a manuscript entitled “Fabrication of Compressed Hosiery and Measurement of its Pressure Characteristic Exerted on the Lower Limbs”, which I submit for possible publication in the Journal of Visualized Experiments. All of the authors agree to the submission of this paper. In this article, we present the two models: cylinder model and conical model to predict the pressure of graduated compression stockings. Additionally, we also studied the influence of fabrication parameters on the stockings fabric structure. The entire experimental and numerical study will provide the essential structure-properties connection and simple mechanism study basement to the pressure characteristic design of graduated compression stockings. We thank you for considering this work and look forward to your response.

Your sincerely,
Hong Xie

TITLE:

Fabrication of Compressed Hosiery and Measurement of its Pressure Characteristic Exerted on the Lower Limbs

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KEYWORDS:

pressure, compressed hosiery, lower limbs, fabrication, cylinder model, Interface sensor

SUMMARY:

This article reports fabrication, structure and pressure measurement of compressed hosiery by employing direct and indirect methods.

ABSTRACT:

This article reports the pressure characteristic measurement of compressed hosiery via direct and indirect methods. In the direct method, an interface sensor is used to measure the pressure value exerted on the lower limbs. In the indirect method, the necessary parameters mentioned by the cone and cylinder model are tested to calculate the pressure value. The necessary parameters involve course density, wales density, circumference, length, thickness, tension, and deformation of the compressed hosiery. Compared with the results of the direct method, the cone model in the indirect method is more suitable for calculating the pressure value because the cone model considers the change in radius of the lower limb from the knee to the ankle. Based on this measurement, the relationship among fabrication, structure, and pressure is further investigated in this study. We find that graduation is the main influence that can change

the wales density. On the other hand, elastic motors directly affect the course density and the circumference of the stockings. Our reported work provides the fabrication-structure-pressure relationship and a design guide for gradually compressed hosiery.

INTRODUCTION:

Compressed hosiery (CH) provides pressure on the lower limb. It can press the skin and further change the vein radius. Thus, the venous blood flow velocity is raised when the patient is dressed in compressed hosiery. CH and other compressed garments could improve venous circulation in the lower limbs[1-4]. The therapeutic performance was dependent on the pressure characteristics of the CH[5]. It was widely believed that raw material and CH structure have a great influence on CH pressure characteristics. Elastane yarn in CH was primarily responsible for the pressure characteristics according to some published research[6]. For example, Chattopadhyay[7] reported the pressure characteristics of knitted circular stretch fabrics by adjusting the feed tension of elastane yarn. In addition, Ozbayraktar[8] also determined that the density of elastane yarn increased while the extensibility of CH decreased. Additionally, loop length[9], knitted pattern[9], and linear density of the yarns[7,10] also exhibited the effects on the pressure characteristics.

A numerical model was presented to inspect the generation mechanism of the pressure characteristics of the CH. Laplace's Law was used for predicting the pressure values. Thomas[11] introduced Laplace's Law into pressure prediction by combining pressure, tension, and body limb size. Similar work also was reported by Maklewska[12]. To precisely predict the pressure values exerted by the fabric, they presented a semi-empirical equation that was composed of the fitted stress-strain equation and Laplace's Law. Additionally, Young's modulus was presented by Leung[13] to describe elongation of the CH.

The above-mentioned numerical studies showed deviated experimental results due to ignorance of the CH thickness[14]. In addition, some researchers believed that the hypothetical cylinder involved in Laplace's Law was inappropriate to describe the body limbs because the radius of the lower limbs from the thigh to the ankle is not constant but gradually decreases. By combining the thick cylinder theory and Laplace's Law, Dale[14] and Al Khaburi[15,16] respectively proposed numerical models to investigate the pressure exerted by the CH with multiple layers. Sikka[17] presented a new cone model with a gradually decreased radius from the thigh to the ankle.

The pressure characteristics intrinsic to CH were difficult to quantitatively study because most of the experimental CHs in previous studies were usually purchased commercially. The influences such as pattern, yarn, raw material were uncontrollable. Therefore, in this study, the experimental CHs were controllably fabricated in house. Moreover, this study aims to provide two methods involving direct method and indirect method to measure the pressure characteristics. In the direct method, an interface sensor (**Table of Materials**) is placed between the skin and textiles to directly measure the pressure value. On the other hand, in the indirect method, the tension and some structure parameters of the CH sample dressing on the artificial lower limb are firstly measured. Then, the results are substituted into the cone model and the cylinder model to calculate the pressure value. The pressure values obtained as a result of the two methods are contrasted and analyzed to find a more appropriate model. The presented methods provide a guideline to the experimental measurement of pressure exerted by the compressed garment.

PROTOCOL:

1. Fabrication of CH

1.1. Programming

1.1.1. Open the STAT-Ds 615 MP stocking software and select **Plain fabric** to create a new sock construction.

1.1.2. Select the following contents in order: **Double welt 1 feed**, **Transfer without pattern**, **Plain medical leg from double welt 1 feed**, **Begin heel from plain medical leg**, **End of heel and plain medical foot**, **Begin toe from plain foot 1f**, **Plain toe with rosso and clip**, **Sock release without turning device**, and **End of sock**. Press **OK** button to complete the sock design.

1.1.3. Select **200** under the **Needle**. Export the program file in a USB flash disk.

1.1.4. Press **Quasar** to change the fabrication parameters. At the bottom of the window, press any one of blue buttons in the **GRADUATION** row to open a new window. For fabricating the CH with different structure, input **500** in the column cylinder **S** and **E**. Press **OK** to complete the setup.

1.1.5. At the bottom of the window, press any one of blue buttons in the row **ELASTIC MOTORS** to open a new window. Input **800** in the **WELT** row, column **S** and **E**. Input **650** in the row **ANKLE**, column **S** and **E**. Press **OK** to complete the setup.

1.1.6. Repeat steps 1.1.4 and 1.1.5. Respectively input **650** and **800** when adjusting **GRADUATION**. Respectively input **1000** and **1200** in the **WELT** row, and keep the **ANKLE** row as **650** when adjusting **ELASTIC MOTORS**.

NOTE: The elastic motors could control the tension of the elastane yarn. Fabricated CH should ensure that the tightness gradually increased from knee to ankle. Here, the elastic motor number in the **ANKLE** is fixed (650), while the elastic motor number in the **WELT** is changed (800, 1000, 1200) to fabricate CH samples with different tightness. The graduation could control the loop size of the whole CH sample. Larger loops usually result in looser CH, while smaller loops always generate a tight CH sample. Thus, we respectively input 500, 650, and 800 as the graduation. Finally, program files with altered elastic motors and graduation are generated.

1.2. Knitting

1.2.1. Prepare the ground yarn and elastane yarn on the CH fabrication machine.

1.2.2. Turn on the machine, insert the USB flash disk, and select the program file obtained from step 1.1.3. The machine automatically fabricates the CH sample. Alphabetically number these samples from A to I.

NOTE: **Table 1** displays the fabrication parameters of these CH samples.

2. Direct measurement

NOTE: All of the CH samples should be conditioned for 24 h in standard atmospheric environment (23 °C, 65% relative humidity [RH]) prior to measurement. The CH samples are dressed on the artificial lower limb to test the pressure value. All measurements should be performed three times to calculate the average value and decrease the error.

2.1. Mark the lines on the CH sample dressing on the artificial lower limb.

2.1.1. Dress a CH sample on the artificial lower limb.

2.1.2. Mark six evenly spaced circle lines on the CH sample. From knee to ankle, number these lines as line 6, 5, 4.... Thus, these lines divide the CH sample into five parts, as shown in **Figure 1a**.

2.2. Pressure measurement

2.2.1. Respectively, place the interface pressure sensor under part 1 of the CH sample in four directions: anterior, posterior, medial, and lateral.

2.2.2. Run the measurement software and select the appropriate serial port **COM**. Set the minimum threshold value as **0**.

2.2.3. Move the button to **Start Measurement**. The 1−4 real-time channel displays the pressure data.

2.2.4. Move the button to **Stop Measurement** after the pressure data is stable. The software automatically exports the pressure data.

2.2.5. Place the interface press sensors under other parts of CH sample and repeat steps 2.2.1−2.2.4.

2.3. After pressure measurement of the whole CH sample, remove the CH sample and then dress another CH sample on the artificial lower limb to prepare for the next measurement.

3. Indirect measurement

NOTE: The experiments here measure the necessary parameters of the cone and cylinder model. These parameters contain the deformation and structure parameters of the dressing and undressed CH samples, thickness, tension. All the CH samples should be conditioned for 24 h in standard atmospheric environment (23 °C, 65% RH) prior to measurement. All measurements should be performed three times to calculate the average value and decrease the error.

3.1 Structure parameter measurement of CH samples

3.1.1. Dress a preceding CH sample on an artificial lower limb.

3.1.2. Measure the total length (L) of each CH sample by using a tape.

3.1.3. Measure the course density and the wales density of each divided part by using a pick glass.

3.1.4 Measure the circumference (c) of each circle line with tape. Then, calculate the circumference (w) of each divided part of the CH sample by averaging the circumferences (c) of the neighboring circle lines.

3.1.5 Remove the CH sample and then dress another sample on the artificial lower limb to prepare for next measurement.

3.1.6. Measure the circumference (c') of each circle line of an undressed CH sample. Then, calculate the circumference (w') of each divided part of CH sample by averaging the circumferences of the neighboring circle lines.

3.1.7. Measure the course density and the wales density of the same divided part of the undressed CH sample.

3.2. Thickness measurement

3.2.1. Place a CH sample smoothly on the steel round table of the thickness gauge.

3.2.2. Turn on the thickness gauge to let another steel round slowly fall down and press upon the sample piece. The screen displays the thickness data (t).

3.2.3. Move the sample and repeat steps 3.2.1 and 3.2.2 to test the thickness of other parts.

3.3 Tensile experiment

3.3.1. Cut all the CH samples along the marked circle lines.

3.3.2. Grip each CH piece by using two clamps of the tensile testing instrument.

3.3.3. Open the software for tensile experiment, input 5 N as the initial tension, 10 mm/s as the tensile speed, and 200 mm as the initial tensile length. Keep the default setup for the other fields.

3.3.4. Press the **START** button on the tensile instrument to run tensile experiment automatically.

The computer then exports real-time stress and strain on the screen. The tensile experiment automatically stops when the CH piece is broken.

3.3.5. Remove the CH piece and attach another CH piece to the tensile testing instrument. Repeat steps 3.3.3−3.3.4.

4. Theoretical calculation

NOTE: The cylinder model and cone model are employed in the indirect measurement to calculate the exerted pressure. Each CH sample is separated into five parts from the knee to the ankle. In the cylinder model, human limbs are described as a cylinder with a constant radius while the radius of the limb is variable in the cone model. The schematic diagrams are illustrated in **Figure 1b** and **Figure 1c**. All calculation steps are performed in Matlab 2018a and the calculation program can be found in the **Supplemental Coding File**.

4.1. Cylinder model

4.1.1. According to the measured results obtained from step 3.1.3−3.1.5, calculate the circumference difference (D) between the dressed CH and the undressed CH using the following equation:

$$D_i = w_i - w_i' \qquad (1)$$

where i is the number of CH piece that is separated by marked circle lines. It is numbered according to the circle line number.

4.1.2. Fit the stress-strain curve obtained in step 3.3.4 using an appropriate linear equation. The slope of the linear equation is the tensile modulus E.

4.1.3. Calculate the tension in the dressing CH (T) by employing the equation:

$$T_i = E_i \cdot D_i \qquad (2)$$

NOTE: **Supplemental Table 1** displays the obtained original tensile modulus E and tension T.

4.1.4. Based on the cylinder model and the thin wall assumption[15], express the exerted pressure of CH piece i as:

$$p_i = \frac{T_i \cdot t}{r_{w,i}} \qquad (3)$$

where r is the radius of divided part and equals to $\frac{w}{2\pi}$, t is the thickness of CH sample, and T is the tension calculated from step 4.1.3.

4.1.5. Calculate all the exerted pressure of CH pieces following steps 4.1.1−4.1.4.

4.2. Cone model

4.2.1. Calculate the exerted pressure of the CH piece i by the following equation[14]:

$$p_i = \frac{T_i\sqrt{l^2 - \left(r_{c,i+1} - r_{c,i}\right)^2}}{5l^2 \cdot r_{c,i+1}} \qquad (4)$$

where r_c is the radius of circle line and equals to $\frac{c}{2\pi}$, T is the tension calculated from step 4.1.3, l is the length of each divided piece and can be calculated by $l = L/5$ (herein, L is measured following step 3.1.2).

REPRESENTATIVE RESULTS:

Course density gradually increases from the knee to the ankle in **Figure 2a**. This is explained by the influence of the elastic motor. From the knee to the ankle, the increased elastic motor gradually generates increasing tension from part 5 to part 1 in the CH fabrication process. Thus, the CH sample is gradually frapped and the loop number per cm is increased in the course direction. The experimental lines in **Figure 2b** can be divided into three groups: ABC, DEF, GHI. Group ABC is fabricated with the smallest graduation value and obtains the highest wales density, while group GHI is produced by the largest graduation value and gets the lowest wales density. In the fabrication process, graduation affects the sinking depth of the needle. Larger sinking depth will generate longer loops, and the loop number per cm along the length direction will decrease. Thus, the CH samples fabricated with the highest graduation value obtain the lowest wales density and vice versa. **Figure 2c** and **Figure 2d** exhibit the circumference of the divided parts on the undressed and the dressed CH sample.

In order to investigate the influence of fabrication on the structure, ANOVA is employed to analyze the data and the results are listed in **Table 2**. The sig. in **Table 2** represents the significance level that describes the influence. The data exhibited the obvious effects of elastic motors on the circumference and the course density of divided parts. Graduation is a main effect on the wales density. The details of structure parameters can be found in **Supplemental Table 2**.

Pressure data obtained from direct and indirect measurement is displayed in **Figure 3**. From part 1 to part 5 (from the ankle to the knee), the exerted pressure magnitude of all CH samples gradually declines. It is clear that the triangle symbols slightly deviate from the circle symbols. This indicates that the predicted pressure data from the cylinder model is inconsistent with the measured pressure. While, comparing with measured pressure, the cone model demonstrates good agreement. To further quantitatively study the differences between the cone model and the cylinder model, the Spearman correlation method is used to analyze all the data (**Figure 4**). The correlation coefficient between the cone model and the measured pressure is 0.9914, which is higher than 0.9221 that represents the correlation coefficient between the cylinder model and the measured pressure. Therefore, the cone model is a better model to predict the pressure characteristic than the cylinder model. All the measured and predicted pressures could be found in **Supplemental Table 3** and **Supplemental Table 4**.

FIGURE AND TABLE LEGENDS:

Figure 1: The numerical model of lower limb. (**a**) The separated five parts divided by six circle lines on the lower limb, (**b**) the lower limb model described by the cylinder model, and (**c**) the lower limb model described by the cone model. This figure has been modified from Zhang et al.[18].

Figure 2: Structure measurement of CH. (**a**) Course density, (**b**) wales density, (**c**) circumference of divided parts on the original CH, and (**d**) circumference of divided parts on the wearing CH. The error bar represents the standard deviation of data. This figure has been modified from Zhang et al.[18].

Figure 3: Measured and calculated pressure values. ○ = measured results, △ = cylinder model, and * = cone model. This figure has been modified from Zhang et al.[18].

Figure 4: Correlation between the measured and calculated pressure values. This figure has been modified from Zhang et al.[18].

Table 1: Fabrication parameters of CH samples.

Table 2: ANOVA results to display the effects of fabrication parameters on the CH structure.

Supplemental Table 1: The obtained parameters tension (N) and tensile modulus (kPa).

Supplemental Table 2: The measured data of structure parameters.

Supplemental Table 3: Measured pressure characteristics (kPa).

Supplemental Table 4: Predicted pressure results from cylinder model and cone model (kPa).

DISCUSSION:

In this study, we provide two methods to measure the exerted pressure of CH samples and these methods can be used to measure the exerted pressure of other garment dressing on the skin. In the direct method, the CH sample is dressed on the artificial lower limb and the interface sensor is placed under the CH sample. The pressure value can be displayed on the screen using data collection software. To compare with the direct method, we also supply an indirect method. Two theories involving the cylinder model and the cone model are employed to calculate the pressure. In order to obtain the pressure distribution, the CH sample is separated into five parts by marking six evenly spaced circle lines (**Figure 1a**). The necessary structure parameters including course density, wales density, length, circumference, and thickness are measured on each CH part dressed on the artificial lower limb, as well as on each undressed CH part. To obtain tensile modulus distribution, the CH sample is cut into five pieces along the circle lines and each piece is stretched on the tensile experiment until it is broken. Combined with tensile modulus and structure parameters, the pressure values calculated by cone model and cylinder model are provided.

We also demonstrate the correlation analysis between the direct method and the indirect method (**Figure 4**). The correlation analysis confirms that the cone model is a better model to predict the pressure characteristics than the cylinder model because of the change in limb radius in the cone model. Thus, the cone model can be employed to effectively predict the pressure distribution of a compressed garment. The methods mentioned in this article also supply experimental ideas and a guide to the pressure measurement of compressed garment.

Additionally, we fabricate the CH samples instead of purchasing commercially. Thus, we can further explore the relationship between the CH structure and its fabrication. In the software of stocking fabrication machine, we adjust **Graduation** and **Elastic Motors** to change the structure of the final CH. **Graduation** is set as 350, 500, and 650; **Elastic Motors** is set as 650-800, 650-1,000, and 650-1,200 (welt-ankle). Elastane yarns with 130, 155, 190 tex are used in the knitting process. The fabrication parameters are listed in the **Table 1**. Through the ANOVA method, the influence of fabrication parameters on the structure is investigated. Due to the limit of the experimental condition, other values of **Graduation** and **Elastic Motors** are not employed and the yarns with other fineness are also not applied. We will further study the details of each fabrication parameter in the future. The method and corresponding results presented in this work have experimental significances in the knitting field.

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DISCLOSURES:
The authors have nothing to disclose.

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Fig1

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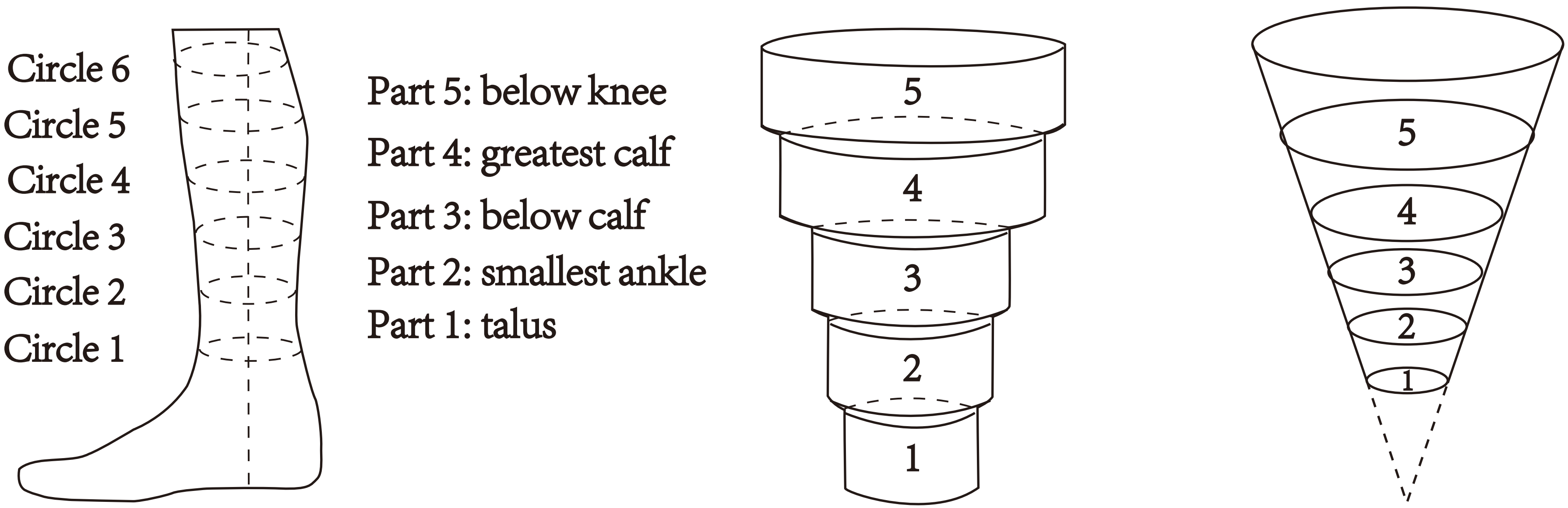


(a) (b) (c)

Figure 2

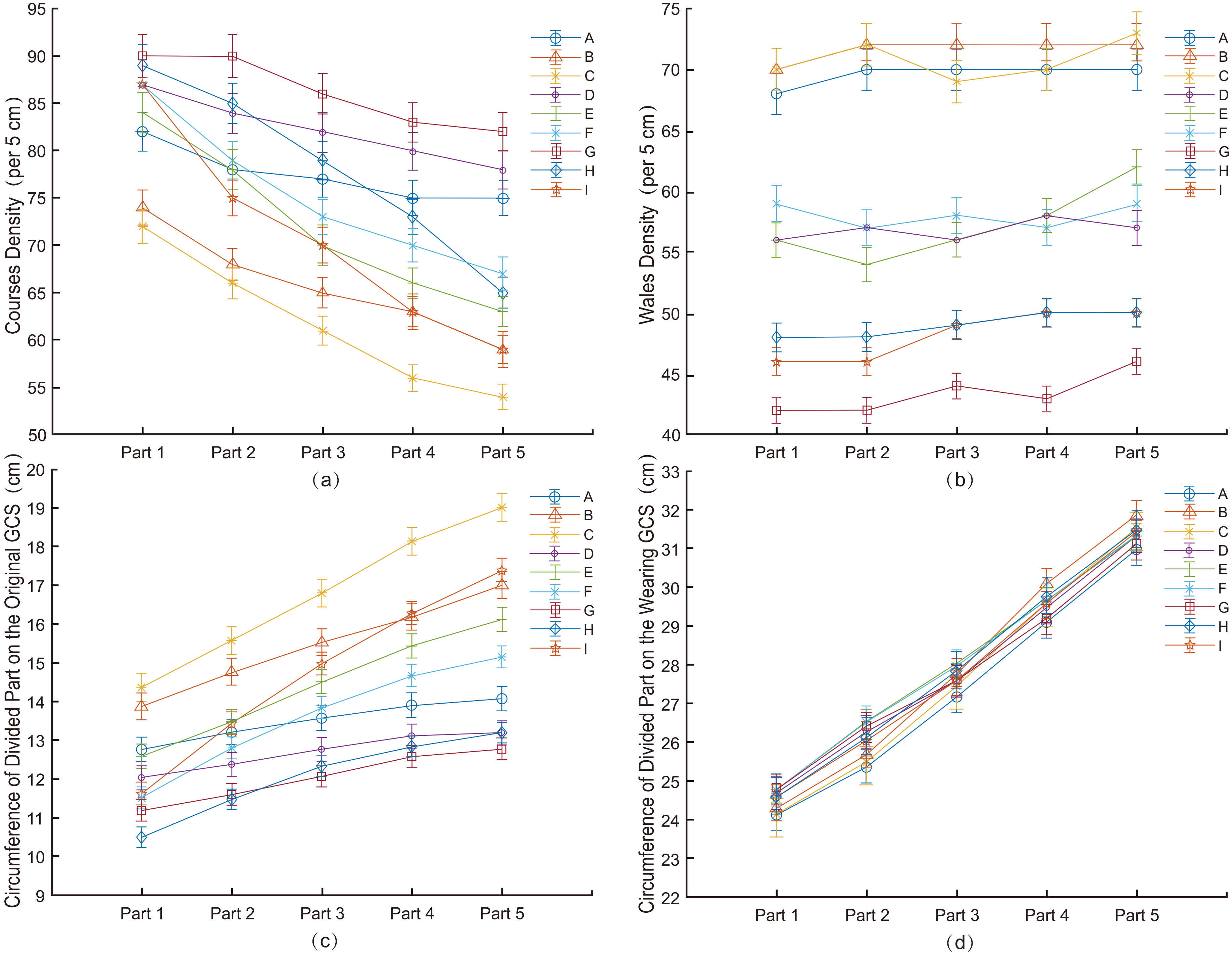

Courses Density (per 5 cm)
95
90
85
80
75
70
65
60
55
50
Part 1
Part 2
Part 3
Part 4
Part 5
A
B
C
D
E
F
G
H
I
(a)
Wales Density (per 5 cm)
75
70
65
60
55
50
45
40
(b)
Circumference of Divided Part on the Original GCS (cm)
20
19
18
17
16
15
14
13
12
11
10
9
(c)
Circumference of Divided Part on the Wearing GCS (cm)
33
32
31
30
29
28
27
26
25
24
23
22
(d)

Figure 3

Click here to access/download;Figure;Fig-3.ai

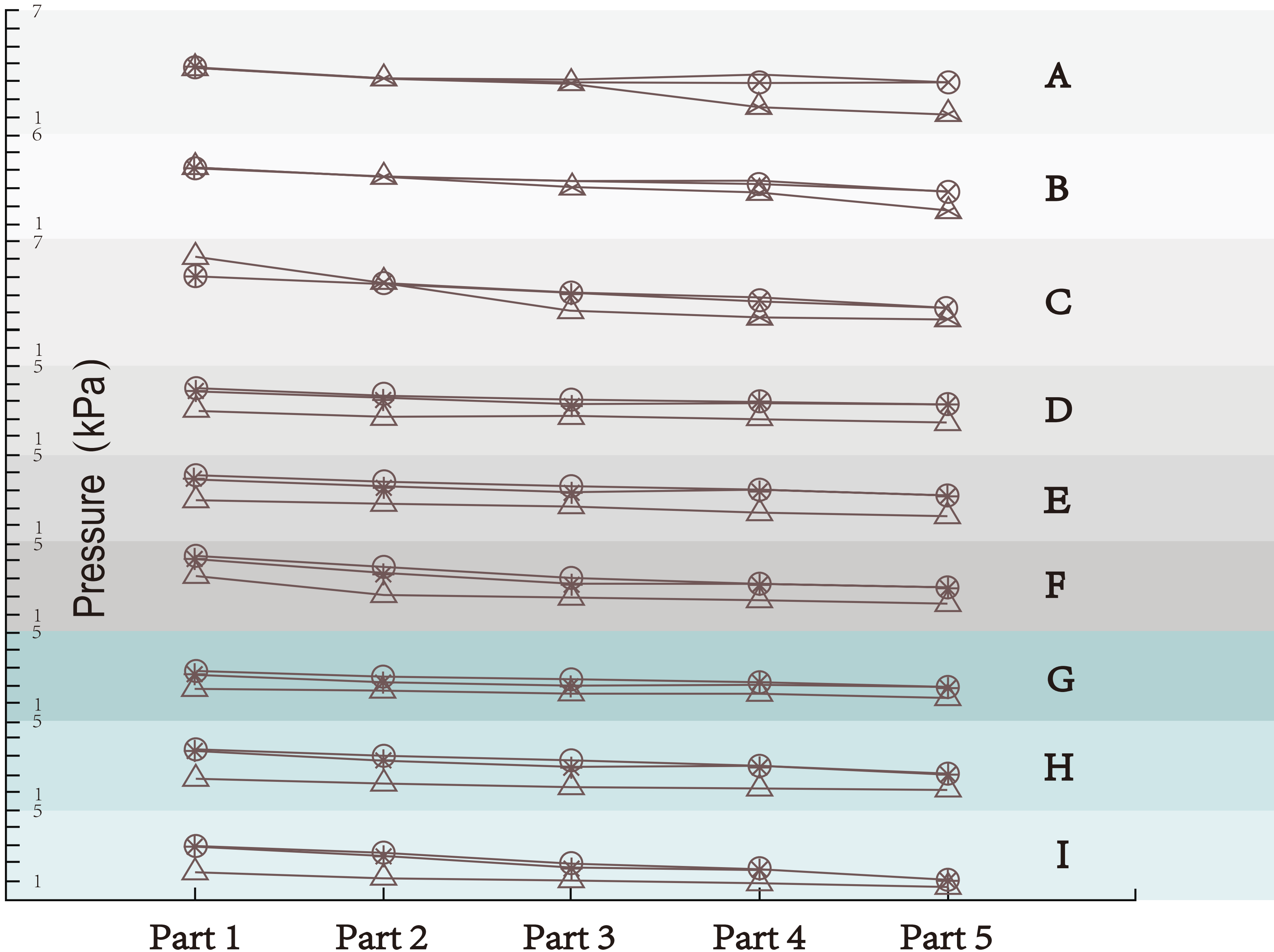
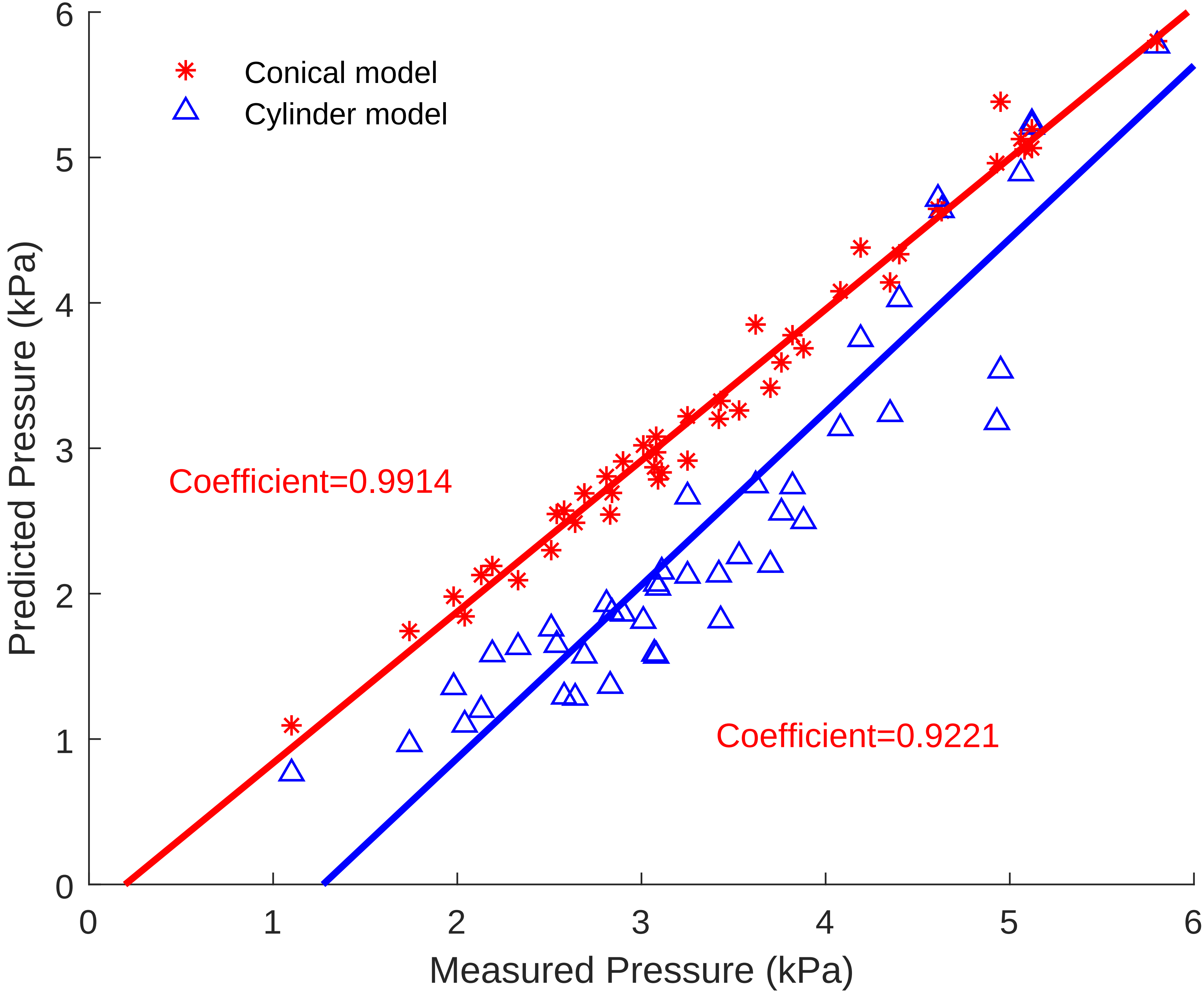


Figure 4



Predicted Pressure (kPa)
Measured Pressure (kPa)
Conical model
Cylinder model
Coefficient=0.9914
Coefficient=0.9221
0
1
2
3
4
5
6

Table 1 Click here to access/download;Table;Table1.xlsx

CH samples	Graduation	Elastic motors (from circle 6 to circle 1)	Elastane yarn fineness (tex)
A	350	650–800	190
B	350	650–1,000	155
C	350	650–1,200	130
D	500	650–800	155
E	500	650–1,000	130
F	500	650–1,200	190
G	650	650–800	130
H	650	650–1,000	190
I	650	650–1,200	155

	Graduation	Elastic motors	Elastane yarn fineness
Sig. Cross density	0.0459	0.0302	0.2238
Sig. Wales density	0.0025	0.1435	0.2652
Sig. Circumference	0.0529	0.0466	0.1071

Name of Material/ Equipment	Company	Catalog Number
Artificial lower limb	Dayuan, Laizhou Electron Instrument Co., Ltd.	YG065C
CH fabrication machine	Hongda, Co., Ltd.	YG14N
Elastane yarn	MathWorks, Co., Ltd.	2018a
FlexiForce interface pressure senso	Qile, Co., Ltd.	Y115B
FlexiForce measurement software	Santoni, Co., Ltd.	GOAL 615MP
Ground yarn	Santoni, Co., Ltd.	
Matlab software	Santoni, Co., Ltd.	
Mechanical testing instrument and software	Santoni, Co., Ltd.	GOAL 615MP
Pick glass	Shenmei, Inc.	F002
STAT-Ds 615 MP stocking software	Tekscan, Inc.	A201
Thickness gauge	Weike, Co., Ltd.	1lbs

Comments/Description

Used for measuring the strength of stockings. The employing test standard is ISO 13934-1-2013, metioned this in section 3.3

Used for measuring the thickness of stockings, the test standard is ISO 5084:1996, metioned this in section 3.2

Used for calculating the pressure, mentioned this in section 4.

It is composed of magnifying glass with a fixed ruler. Used for counting the loops number per cm in the fabricated CH, metioned this in the sc

Used for fabricating stockings, metioned this in section 1.2

It is a kind of coverd yarn which is composed of 80% rubber and 20% viscose, metioned this in section 1.2.1

It is a kind of coverd yarn which is composed of 30% polyamide and 70% cotton, metioned this in section 1.2.1

Used for programing the fabrication parameters, metioned this in section.1.1

A standard artificial femal with 160 cm height. The size was consited with Chinese Standard GB 10000-1988. The artificial femal was made by

Used for measuring the pressure on the skin, metioned this in section 2.2.1

Used for recording the pressure, metioned this in section 2.2.2-2.2.4.

tion 3.1.3 and 3.1.7.

glass-reinforced plywood and covered by fabric. Mentioned this in section 2.1.

Dear, editor. We've corrected the problems you mentioned. We didn't mark all of the corrections, because we corrected many errors and rephrase many sentences. We also provided a point to point response as following:

1. The whole manuscript has been read again. We corrected the language problems.

2. Our corrections are based on your updated manuscript.

3. The tile has been revised.

4. The summary has been revised.

5. The abstract has been revised. We extract two methods from the whole study. And introduce these methods in the the new abstract. Because, JOVE is a method-based journal. Thus, we detailedly describe the method and corresponding results.

6. The goal of this article has been revised. Because JOVE is a method-based journal, we've corrected the rephrase. We presented two methods and introduced the steps of these methods. We also mentioned the research significance.

7. We also revised the discussion part. In the 1st paragraph we introduced the critical steps in the protocol. In the 2nd paragraph we introduced the application of ANOVA method. In the 3rd paragraph, we discussed the limitations of the method, the significance of the methods in knitting and compressed garment field and the future applications these methods.

8. We've submitted multipanel figures (A, B, C, etc.) as a single image file that contains the entire figure (Fig.2).

9. We've uploaded each table individually to the system as an .xlsx file including supplemental tables.

10. We've mentioned all of the relevant suppliese, software, material in the Table of Materials, and sorted the materials alphabetically by material name.

11. The comments attached in the manuscript are addressed here:

(1) the error of reference 10 has been corrected.

(2) we revised the goal of whole article at the end of the introduction part.

(3) The head of section 2.2 has been revised.

(4) The explanation of pick glass has been deleted. And the explanation is added into the Table of Material.

(5) It seems that there are many confused part in the original protocol. Thus, we rephrase the whole protocol. We hope the new protocol will exhibit clearly.

(6) The section 4 theoretical calculation is not appropriate for filming.

(7) The error bar exhibits the standard deviation of data in Fig.2. We also added this sentence in

the caption of Fig.2.

(8) We also added the explanation of Sig. in the 2nd paragraph in the representative results part.

(9) We reference all of the tables in the manuscript.

Supplemental Table 1

Parameters	Sample	A	B	C	D	E	F	G	H	I
Tension	Part 1	52.33 ± 4.87	45.2 ± 4.35	44.45 ± 4.15	46.88 ± 4.03	48.16 ± 4.43	51.53 ± 3.01	44.39 ± 3.41	52.25 ± 3.95	46.08 ± 2.15
	Part 2	50.12 ± 4.65	44.35 ± 4.15	43.77 ± 4.45	46.26 ± 4.04	47.54 ± 4.53	47.58 ± 2.83	42.56 ± 3.13	50.75 ± 3.55	42.84 ± 2.65
	Part 3	53.22 ± 4.25	45.33 ± 4.05	41.64 ± 4.05	45.18 ± 4.09	47.01 ± 4.23	42.65 ± 2.73	42.4 ± 3.27	50.25 ± 3.32	35.58 ± 3.01
	Part 4	59.58 ± 4.95	49.4 ± 4.95	42.29 ± 3.95	51.12 ± 4.13	49.7 ± 3.03	44.29 ± 2.93	45.56 ± 2.83	52.33 ± 3.45	34.66 ± 2.97
	Part 5	58.34 ± 5.35	44.17 ± 4.65	37.28 ± 3.65	47.3 ± 4.63	43.66 ± 3.13	39.35 ± 3.01	40.49 ± 2.96	42.47 ± 2.35	21.54 ± 2.81
Tensile modulus	Part 1	13.59	15.25	20.2	4.69	5.2	6	2.67	2.58	2.67
	Part 2	12.47	14.51	17.47	3.8	4.87	4.57	2.47	2.47	2.65
	Part 3	11.54	12.77	12.61	3.75	4.81	4.5	2.29	2.21	2.54
	Part 4	8.18	11.83	11.88	3.58	4.38	4.48	2.28	2.13	2.45
	Part 5	7.13	8.99	11.84	3.24	4.11	4.04	2	2.07	2.2

Parameters	Sample	A	B	C	D	E	F	G	H
Cross density (per 5 cm)	Part 1	82 ± 2	74 ± 2	72 ± 2	87 ± 2	84 ± 2	87 ± 2	90 ± 2	89 ± 2
	Part 2	78 ± 2	68 ± 2	66 ± 1	84 ± 2	78 ± 2	79 ± 2	90 ± 2	85 ± 2
	Part 3	77 ± 2	65 ± 2	61 ± 1	82 ± 2	70 ± 2	73 ± 2	86 ± 2	79 ± 2
	Part 4	75 ± 2	63 ± 2	56 ± 1	80 ± 2	66 ± 2	70 ± 2	83 ± 2	73 ± 2
	Part 5	75 ± 2	59 ± 2	54 ± 1	78 ± 2	63 ± 1	67 ± 2	82 ± 2	65 ± 2
Wales density (per 5 cm)	Part 1	68 ± 2	70 ± 2	70 ± 1	56 ± 2	56 ± 2	59 ± 2	42 ± 1	48 ± 1
	Part 2	70 ± 2	72 ± 2	72 ± 2	57 ± 2	54 ± 2	57 ± 2	42 ± 1	48 ± 1
	Part 3	70 ± 2	72 ± 2	69 ± 2	56 ± 2	56 ± 2	58 ± 2	44 ± 2	49 ± 1
	Part 4	70 ± 2	72 ± 2	70 ± 2	58 ± 2	58 ± 2	57 ± 2	43 ± 1	50 ± 1
	Part 5	70 ± 2	72 ± 2	73 ± 2	57 ± 2	62 ± 2	59 ± 2	46 ± 1	50 ± 1
Circle girth of the wearing CH (cm)	Circle 1	23.75 ± 2.1	23.81 ± 2.3	23.69 ± 1.86	23.73 ± 2.2	23.75 ± 2.18	23.79 ± 1.76	23.81 ± 1.86	23.88 ± 1.88
	Circle 2	24.53 ± 2.3	24.8 ± 2.4	24.65 ± 1.91	25.69 ± 1.87	25.81 ± 2.27	25.77 ± 1.83	25.87 ± 1.96	25.3 ± 2.18
	Circle 3	26.2 ± 2.4	26.58 ± 2.1	26.37 ± 1.59	26.89 ± 1.9	27.28 ± 2.31	27.29 ± 1.88	27.02 ± 2.14	26.94 ± 2.68
	Circle 4	28.17 ± 2.5	28.97 ± 2.1	28.54 ± 2.18	28.32 ± 2.03	28.82 ± 2.45	28.66 ± 1.98	28.28 ± 2.21	28.75 ± 2.98
	Circle 5	30.04 ± 1.9	31.25 ± 2.9	30.71 ± 1.98	30.67 ± 2.67	30.56 ± 2.46	30.71 ± 2.14	30.16 ± 2.18	30.78 ± 3.48
	Circle 6	31.92 ± 2.5	32.48 ± 3.1	32.42 ± 1.96	32.01 ± 2.77	32.12 ± 2.56	32.02 ± 2.22	32.12 ± 2.48	32.15 ± 2.77
Circle girth of the original CH (cm)	Circle 1	12.48 ± 1.1	13.4 ± 1.2	13.65 ± 1.15	11.8 ± 1.29	12.28 ± 1.21	10.78 ± 1.32	10.95 ± 1.04	10.05 ± 1.04
	Circle 2	13.05 ± 1.2	14.35 ± 1.1	15.08 ± 1.16	12.28 ± 1.35	12.9 ± 1.23	12.25 ± 1.21	11.45 ± 1.09	10.95 ± 1.09
	Circle 3	13.35 ± 1.1	15.18 ± 1.3	16.08 ± 1.21	12.48 ± 1.39	14.02 ± 1.32	13.35 ± 1.31	11.75 ± 1.19	12.01 ± 1.18
	Circle 4	13.81 ± 1.1	15.88 ± 1.1	17.55 ± 1.23	13.05 ± 1.41	15 ± 1.15	14.35 ± 1.33	12.4 ± 1.25	12.65 ± 1.3
	Circle 5	14 ± 1.3	16.5 ± 1.4	18.72 ± 1.25	13.15 ± 1.31	15.9 ± 1.28	15 ± 1.43	12.75 ± 1.36	13.01 ± 1.32
	Circle 6	14.15 ± 1.4	17.51 ± 1.4	19.34 ± 1.29	13.25 ± 1.35	16.35 ± 1.35	15.3 ± 1.45	12.78 ± 1.34	13.38 ± 1.31
Thickness (mm)		1.15 ± 0.1	1.11 ± 0.1	1.08 ± 0.12	1.28 ± 0.13	1.23 ± 0.14	1.16 ± 0.16	1.43 ± 0.14	1.29 ± 0.19

I
87 ± 2
75 ± 2
70 ± 2
63 ± 2
59 ± 1
46 ± 1
46 ± 1
49 ± 1
50 ± 1
50 ± 1
23.79 ± 2.18
25.42 ± 2.48
26.71 ± 2.78
28.58 ± 3.18
30.62 ± 3.28
32.3 ± 2.59
10.75 ± 1.06
12.5 ± 1.09
14.35 ± 1.23
15.6 ± 1.31
16.95 ± 1.39
17.8 ± 1.51
1.3 ± 0.14

Supplemental Table 3

Parameter	Sample	A	B	C	D	E	F	G	H	I
Measured pressure	Part 1	5.8 ± 0.27	5.12 ±	5.08 ± 0.29	3.76 ±	3.88 ± 0.21	4.35 ± 0.32	2.84 ± 0.29	3.43 ± 0.27	3.08 ± 0.21
	Part 2	5.12 ± 0.23	4.63 ±	4.61 ± 0.31	3.42 ±	3.53 ± 0.30	3.7 ± 0.33	2.51 ± 0.24	3.07 ± 0.31	2.64 ± 0.22
	Part 3	5.06 ± 0.21	4.4 ±	4.08 ± 0.33	3.11 ±	3.25 ± 0.29	3.09 ± 0.31	2.33 ± 0.23	2.83 ± 0.32	2.04 ± 0.23
	Part 4	4.95 ± 0.28	4.19 ±	3.62 ± 0.29	3.08 ±	3.01 ± 0.28	2.81 ± 0.29	2.19 ± 0.21	2.58 ± 0.29	1.74 ± 0.19
	Part 5	4.93 ± 0.27	3.82 ±	3.25 ± 0.28	2.9 ±	2.69 ± 0.24	2.54 ± 0.26	1.98 ± 0.19	2.13 ± 0.22	1.1 ± 0.14
Average pressure		5.17	4.4	4.13	3.3	3.27	3.3	2.37	2.81	2.12
Pressure gradient		0.19	0.3	0.47	0.2	0.29	0.45	0.2	0.31	0.47

Supplemental Table 4

Model	Sample	A	B	C	D	E	F	G
Cylinder model	Part 1	5.77	5.24	6.16	2.56	2.5	3.24	1.87
	Part 2	5.21	4.64	4.71	2.13	2.26	2.2	1.76
	Part 3	4.89	4.02	3.14	2.15	2.12	2.04	1.63
	Part 4	3.53	3.75	2.74	2.07	1.81	1.93	1.58
	Part 5	3.18	2.73	2.67	1.86	1.57	1.65	1.36
Conical model	Part 1	5.8	5.06	5.06	3.59	3.69	4.14	2.69
	Part 2	5.19	4.63	4.65	3.2	3.26	3.42	2.3
	Part 3	5.13	4.33	4.08	2.83	2.92	2.79	2.09
	Part 4	5.38	4.38	3.85	3.08	3.02	2.81	2.19
	Part 5	4.96	3.78	3.22	2.91	2.69	2.55	1.98

H	I
1.82	1.57
1.59	1.28
1.37	1.1
1.29	0.96
1.2	0.76
3.32	2.97
2.87	2.49
2.54	1.84
2.57	1.74
2.13	1.09

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