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INVESTIGATION INTO IMPROVING LOOP LENGTH PREDICTION IN WEFT-KNITTED FABRICS USING EXPERIMENTAL AND GEOMETRICAL APPROACHES

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Abstract: *Geometrical models of weft-knitted fabrics aim to capture the spatial geometry of yarn loops by utilising structural and material parameters. This study investigates the accuracy of various geometrical models in predicting loop length (LL) using theoretically and experimentally adjusted yarn diameters. The geometrical models proposed by Chamberlain (1926), Pierce (1947), Leaf and Glaskin (1955), Munden (1960) and Kawabata (1970) were investigated. These models use course and wale spacing and yarn diameter as predictors. The yarn diameter, initially calculated using yarn linear density, was experimentally validated through microscopy-based image analysis. An adjustment factor was introduced by comparing measured yarn diameters to theoretical values to refine model predictions. Results revealed that predictions using adjusted yarn diameters significantly outperformed those using theoretical diameters, with Pierce's model demonstrating the highest accuracy among the tested models.*
Experimental validations were conducted on diverse fabric samples, incorporating wale and course spacing, yarn count, and other structural parameters. Comparisons between theoretical and experimental loop lengths illustrate the efficacy of the adjustment factor in enhancing prediction reliability. Additionally, this study establishes a foundation for future work in automated loop length determination using image analysis of fabric structure, enabling more efficient and accurate predictions in textile engineering. The findings contribute to improved geometrical modeling of weft-knitted fabrics and offer practical applications for the textile industry, particularly in quality control and product design optimisation. Further studies are recommended to expand the scope to other fabric types and modeling techniques.

Keywords*: geometrical modelling, yarn diameter, image analysis, loop length prediction, quality control, product design*

1. INTRODUCTION

Geometrical models of weft knitted fabrics

Geometric modelling is the computer-generated representation of an object's geometry by the extensive use of curves to construct surfaces [1]. The curves can be formed by:

- A set of points;
- Analytical functions;
- Other curves.

Geometrical models of weft-knitted fabrics attempt to obtain the geometric features of the spatial shape of loops in the fabric based on the yarn and knitting parameters. These features define and add value to the textile product [2-3]. Most models are validated by accurately predicting the yarn loop length, *l* (mm), from other structural parameters of the fabric [4-5]. Table 1 summarises the models investigated in this work.

Table 1: *Summary of selected geometrical models of weft-knitted fabrics (Vassiliadis, 2007)*

MODEL	LOOP GEOMETRY	ASSUMPTIONS	LOOP LENGTH EQUATION	PARAMETERS
Chamberlain	-Circular arcs and straight lines	Two-dimensional loop	$l = w(3\pi + \sqrt[3]{13})$	w – wale spacing
Pierce	-Yarn forming course lies on a circular cylindrical surface -Arc tangentially connected to two-line segments	-Wales spacing is four times the yarn diameter -Course spacing is $\sqrt[2]{3}$ times the yarn diameter	$l = \frac{2}{C} + \frac{1}{W} + 5.94D$	C – Courses/mm W – Wales/mm D – Yarn diameter(mm)
Leaf and Glaskin	-Yarn forming course lies on a series of circular cylindrical surfaces -Projection of the loop comprised of tangentially connected arcs	- Wales spacing is four times the yarn diameter - Course spacing is $\sqrt[2]{3}$ times the yarn diameter	$L = 4a\varphi D$ $\varphi = \pi + \sin^{-1}\left\{\frac{C^2D}{\sqrt{C^2 + W^2(1 - C^2D^2)}}\right\}$ $a = \frac{1}{(4WD\sin\varphi)}$	L- Loop length (inch) C- Courses/inch W – Wales/inch D- Diameter(inch)
Munden	-Based on forces resulting from pressure of one loop on another	-Direction of forces considered parallel to the course direction of fabric	$\frac{l}{c} = 1.088\frac{c}{D} + 2\left\{1 + \frac{9}{16}\left(\frac{D}{c}\right)^2\right\}$	c- course spacing (mm) D- Yarn diameter(mm)
Kawabata	-Unit cell structure of quarter loop composed of circular arc and a straight line	-No deformation of unit cell	$\frac{l}{2} = \frac{w}{2} + \frac{3\pi D}{\sqrt[3]{2}} + \sqrt{\left(c - \frac{\pi D}{\sqrt[3]{2}}\right)^2 + \left(\frac{\pi D}{\sqrt[3]{2}}\right)^2}$	w- wale spacing(mm) c- course spacing(mm) D- Yarn diameter(mm)

This paper aimed to evaluate the loop length prediction accuracy of the different models summarised in Table 1 using measured values of loop length (LL), number of courses and wales per cm, and yarn diameter for fine gauge weft knitted fabrics made of 100% combed cotton yarn. The measured yarn diameters were compared to theoretical yarn diameters computed from cotton fibre density and yarn linear densities. This comparison enabled the formulation of an adjustment factor to theoretical values to obtain more realistic estimates of yarn diameter from the yarn's linear density.

2. MATERIALS AND METHODS

For this investigation, 19 cotton weft knitted fabric samples of various area densities and yarn counts corresponding to different loop lengths were selected. The fabrics included 10 single jerseys, 4 single piques, 2 double piques, and 3 multi-tuck piques. The loop lengths recorded for the tuck-containing fabrics were those corresponding to the all-knit courses.

2.1 Measurement of fabric constructional parameters

The fabric samples were conditioned under standard conditions. Courses and wales per cm were measured using a 3x3 cm pick glass according to ISO 14971. The course and wale spacing were obtained by taking the reciprocal of courses per cm and wales per cm, respectively. The loop length was measured using a Shirley crimp tester according to ISO 4915.

2.2 Yarn diameter measurement

The procedure used for measuring the yarn diameter was as follows:

1. Unravel five courses of known YC from a 10cm-by-10cm fabric sample;
2. Place a decrimped segment of one course on the glass slide;
3. View the image on the Motic® microscope video screen;
4. Adjust the clarity of the image such that the edges of the yarn core can be clearly identified;
5. Use the image analysis tool to measure the diameter at five different places along the length of the yarn segment;
6. Repeat steps 2-5 for the other four courses;
7. Compute the average actual yarn diameter, $D_{ac,}$ for the 25 readings obtained.

2.3 Computation of theoretical yarn diameter

The theoretical diameter, D_{th}, in cm, was derived from the yarn linear density as follows:

$$\rho = {}^{m}/_{v} = {}^{m}/_{A\ x\ l} \tag{1}$$

$$A = \frac{\pi D^2}{4} \tag{2}$$

$$\rho = \frac{4m}{\pi d^2} = \frac{4}{\pi \cdot 10^5} \cdot \frac{tex}{d^2} \tag{3}$$

$$d = \sqrt{\frac{4}{\pi \cdot 10^5 \cdot 1.54}} \cdot \sqrt{tex} \tag{4}$$

$$d = 9.1 \cdot 10^3 \cdot \sqrt{tex} \tag{5}$$

Where,

ρ = density of cotton= 1.54 g/cm^3
m= mass of yarn, g
v= volume of yarn, cm^3
A= area of cross-section, cm^2
l = length of yarn, cm

d = diameter of yarn, cm

3. RESULTS AND DISCUSSIONS

Table 2 gives the theoretical and measured diameters of yarns of different counts. Their ratios were computed in order to establish an adjustment factor for the theoretical diameter.

Table 2: Adjustment factor for average different yarn count

Yarn count (Ne)	**12**	**16**	**20**	**24**	**30**	**40**
D_{th} (mm)	0.638	0. 553	0. 494	0. 451	0. 403	0. 349
D_{ac} (mm)	0.341	0.271	0.237	0.208	0.1817	0.175
D_{th}/D_{ac}	1.9	2.0	2.1	2.2	2.2	2.0

Based on the ratios obtained, it was decided to set the adjustment factor to a fixed value of 2.0. The adjusted diameter of a yarn of any count was thus obtained from its theoretical diameter as follows:

$$D_{ad} = \frac{D_{th}}{2.0} \quad \textbf{(6)}$$

Tables 3 and 4 show the values of LL obtained from different theoretical models using the theoretical yarn diameter (corresponding to loop length, LL_{th}) and the adjusted yarn diameter (corresponding to loop length, LL_{ad}), respectively.

Table 3: *Geometrical model predictions of LL using theoretical yarn diameter*

Fabric Code	**Tex**	**LL (cm)**	**Theoretical diameter (cm)**	**Chamberlain model (cm)**	**Pierce model (cm)**	**Leaf and Glaskin model (cm)**	**Munden model (cm)**	**Kawabata model (cm)**
SP4	19.7	0.33	0.040	1.36	0.39	-	0.85	0.87
SP3	19.7	0.25	0.040	1.05	0.38	-	0.59	0.83
SP2	24.6	0.26	0.045	1.09	0.42	-	0.67	0.92
SP1	29.5	0.30	0.049	1.25	0.46	-	0.74	1.02
SJ9	36.9	0.33	0.055	1.05	0.53	0.38	0.59	1.09
SJ8	29.5	0.31	0.049	0.99	0.47	0.35	0.55	0.98
SJ7	24.6	0.28	0.045	0.84	0.43	0.32	0.46	0.89
SJ6	24.6	0.28	0.045	0.93	0.43	0.33	0.51	0.90
SJ5	19.7	0.25	0.040	0.76	0.38	0.27	0.44	0.80
SJ4	19.7	0.26	0.040	0.84	0.40	0.35	0.38	0.80
SJ3	19.7	0.24	0.040	0.79	0.39	0.30	0.42	0.80
SJ2	19.7	0.26	0.040	0.81	0.40	0.34	0.38	0.80
SJ10	39.4	0.35	0.057	1.16	0.54	0.41	0.64	1.14
SJ1	14.8	0.24	0.035	0.78	0.36	0.35	0.30	0.69
MT3	19.7	0.25	0.040	1.12	0.42	0.44	0.39	0.82
MT2	29.5	0.29	0.049	1.05	0.49	0.39	0.51	0.98
MT1	14.8	0.25	0.035	0.86	0.38	0.44	0.27	0.69
DP2	49.2	0.40	0.064	1.71	0.59	-	1.18	1.33
DP1	19.7	0.26	0.040	1.12	0.38	-	0.14	0.84

Figures 2 and 3 show the predictive capabilities of the different models using theoretical and adjusted yarn diameters, respectively. Accordingly, Pierce's model with adjusted yarn diameter gives the highest prediction accuracy.

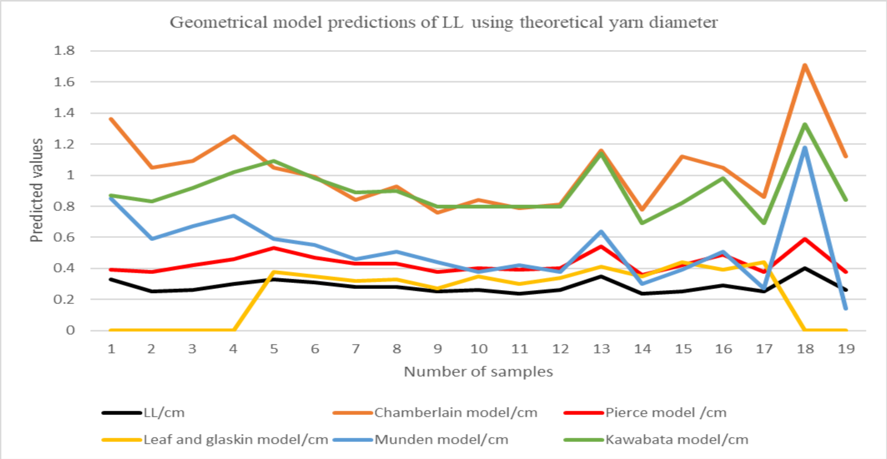

Fig. 2: *Geometrical model predictions of LL using theoretical yarn diameter*

Table 4: *Geometrical model predictions of LL using adjusted yarn diameter*

Fabric Code	Tex	LL (cm)	Adjusted diameter (cm)	Chamberlain model (cm)	Pierce model (cm)	Leaf and Glaskin model (cm)	Munden model (cm)	Kawabata model (cm)
SP4	19.7	0.33	**0.020**	1.36	0.27	0.48	0.85	0.74
SP3	19.7	0.25	**0.020**	1.05	0.26	0.48	0.59	0.71
SP2	24.6	0.26	**0.023**	1.09	0.29	0.50	0.67	0.79
SP1	29.5	0.30	**0.025**	1.25	0.32	0.56	0.74	0.87
SJ9	36.9	0.33	**0.028**	1.05	0.36	0.71	0.59	0.94
SJ8	29.5	0.31	**0.025**	0.99	0.32	0.63	0.55	0.84
SJ7	24.6	0.28	**0.023**	0.84	0.30	0.60	0.46	0.77
SJ6	24.6	0.28	**0.023**	0.93	0.30	0.57	0.51	0.77
SJ5	19.7	0.25	**0.020**	0.76	0.26	0.50	0.44	0.69
SJ4	19.7	0.26	**0.020**	0.84	0.28	0.66	0.38	0.69
SJ3	19.7	0.24	**0.020**	0.79	0.27	0.55	0.42	0.69
SJ2	19.7	0.26	**0.020**	0.81	0.28	0.65	0.38	0.69
SJ10	39.4	0.35	**0.029**	1.16	0.38	0.72	0.64	0.98
SJ1	14.8	0.24	**0.017**	0.78	0.26	0.67	0.30	0.60
MT3	19.7	0.25	**0.020**	1.12	0.30	0.80	0.39	0.71
MT2	29.5	0.29	**0.025**	1.05	0.34	0.73	0.51	0.85
MT1	14.8	0.25	**0.017**	0.86	0.28	0.84	0.27	0.61
DP2	49.2	0.40	**0.032**	1.71	0.40	0.65	1.18	1.14
DP1	19.7	0.26	**0.020**	1.12	0.26	0.49	0.14	0.72

By comparing the results in Table 3 with those of Table 4, it is found that the models give better predictions when using the adjusted yarn diameter. Pierce's model could predict LL with the highest accuracy among all the geometrical models considered.

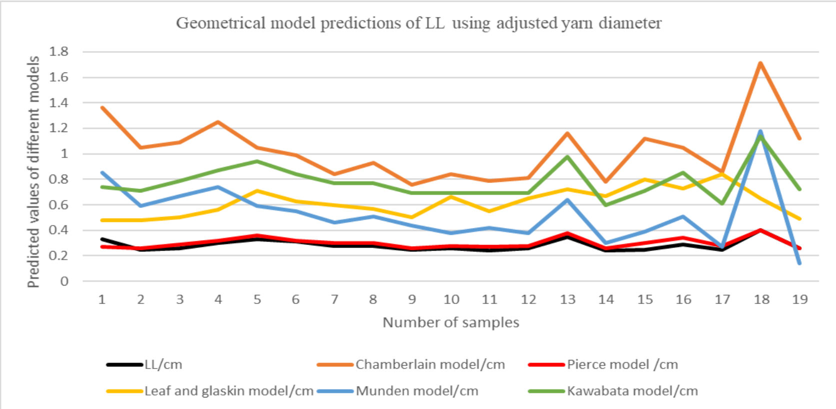

Fig. 3: Geometrical model predictions of LL using adjusted yarn diameter

4. CONCLUSIONS

Experimental data were used to verify the prediction accuracy of various theoretical loop length models. Pierce's model was found to be the most accurate one. All the models gave improved prediction values when an adjustment factor was applied to the theoretical yarn diameter. These findings will be used in future works to obtain the LL from fabric images by counting the number of courses and wales per cm using image analysis methods and deriving the adjusted yarn diameter for the fabric from the input of its YC.

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6. REFERENCES

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