SINGLE WOVEN FABRIC CHARACTERIZATION IN TERMS OF YARN DIAMETER AND AVERAGE FLOAT

THEORETICAL CONSIDERATIONS AND TEST RESULTS

"توصيف القماش المنسوج الآحادي بدلالة قطر الخيط ومتوسط التئيشيف"

"اعتبارات نظرية ونتائج اختبار"

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خلاصه:

يقدم هذا البحث طريقة عملية دقيقة لقياس قطر الخيط وطرفيه نظريًا بناءً على أساس علمي، وفي نفس الوقت، سهلة، وسريعة، وغير معقدة لتصنيف الخيوط بخصائص الخواص الهندسية، والتفاصيل الإنشائية، للقماش المنسوج الآحادي. وقد تم التوصل إلى جميع المعادلات والمتغيرات لإنتاج والإنجاز في هذا البحث ممكن تصنيف الأنماط المنسوجة الآحادية إلى نوعين من الشكل، والمقطع. يتميز الأول بأشكال المستوية بين كل خيوط من المجاورين في القماش، بينما يتميز الثاني بعكس ذلك، واستخدم متوسط التئيشيف، بناءً على التحليل النظري، للتعبير عن التركيب النسبي. وقد تم استخدام قطر الخيط، وطريقة التصنيف لكل من السواء، واللحم، في إيجاد عدد السماك لكل منها (أقصى كثافة) وعن كل كثافة ومدة خيوط لمسافات بحور سماك كثافة التشريحة، ونسبة الكتلية، ومسافة وسائط كثافة إجمالى للخيوط كمترتين لدرجة قيمة السماك، وتضمن درجات إكماح اللحمة، عدد تشابهات اللحمة، وحدة عرض من القماش، ودرجة إكماح اللحمة (عدد تشابهات السواء، وحدة عرض من القماش، ووحدة عرض من التشابهات بإجمالي كثافة القماش). وعدد تشابهات اللحمة. وعدد عرض من القماش، وعدد تشابهات بإجمالي كثافة الصبة، وعدد تشابهات بإجمالي كثافة الصبة. وعدد عرض من القماش، وعدد عرض من التشابهات بإجمالي كثافة الصبة. وعدد عرض من القماش، وعدد عرض من التشابهات بإجمالي كثافة الصبة، وعدد عرض من القماش، وعدد عرض من التشابهات بإجمالي كثافة الصبة، وعدد عرض من القماش، وعدد عرض من التشابهات بإجمالي كثافة الصبة، وعدد عرض من القماش، وعدد عرض من التشابهات بإجمالي كثافة الصبة، وعدد عرض من القماش، وعدد عرض من التشابهات بإجمالي كثافة الصبة، وعدد عرض من القماش، وعدد عرض من التشابهات بإجمالي كثافة الصبة، وعدد عرض من القماش، وعدد عرض من التشابهات بإجمالي كثافة الصبة، وعدد عرض من القماش، وعدد عرض من التشابهات بإجمالي كثافة الصبة، وعدد عرض من القماش، وعدد عرض من التشابهات بإجمالي كثافة الصبة، وعدد عرض من القماش، وعدد عرض من التشابهات إ.......
Knowing fabric weight and thickness enables calculating its volumetric density. The relative weaving density (the ratio between actual yarn density and maximum yarn density) can also be calculated. All expressions are derived using elementary principles. Peirce's model of woven fabrics is modified in such a manner that fabric can be spread onto a plane surface. This methodology lets no need to many instruments used in testing fabrics such as fabric thickness meter, yarn diameter ordinary meter, and yarn crimp tester and helps reduce yarn waste as the amount of consumed yarn can be accurately calculated. It helps also reduce costs of weaving by choosing the suitable weaving machine and its adjustments according to maximum set of yarns and fabric characters, and costs of testing yarns and fabrics.

Key Words:
Cylinders, Yarn Diameter, Warp, Weft, Average Float, Plain and Floated Weaves, Extended Weaves, Weave Angle, Yarn Density, Yarn Crimp Ratio, Yarn Cover Ratio, Fabric Weight, Fabric Thickness, Fabric Volumetric Density, Relative Weaving Density, Tightness, Maximum Tightness.

1- Systematic Problem Solving:

2- Introduction:
Till recently there are only geometrical models that have been suggested to relate fabric parameters to each other [1]. In order to relate crimp altitude to yarn spacing and crimp ratio, Peirce [2] assumed that weave angle is small, but this is not true except in very open structures which is a very special case [3]. Yarn diameter is not easy to be measured accurately with normal methods, and the trials which were carried out to calculate it were based on approximate formulae. The first pure mathematical trial to investigate fabric structure and to describe it through perfect accurate relations was in 1994 [4]. That study dealt with plain square fabric. In terms of yarn count, yarn volumetric density and yarn set, many geometrical parameters could be expressed, such as yarn cover ratio, Weave angle, yarn crimp ratio, fabric weight, fabric volumetric density, and packing density of yarn into the fabric. It could be concluded that maximum yarn cover ratio is $1/\sqrt{3}$ or 0.577. This means that maximum cover factor is 16.1658 as cover factor equals cover ratio multiplied by 28. Based on the assumption that fabric thickness is equal
to the sum of yarn diameter and yarn crimp altitude of warp or weft whichever is more [5], weave angle could be expressed as a function of yarn diameters, yarn spacing, and crimp altitude as a ratio of the sum of warp and weft diameters. Crimp interchange has been analyzed and the state of zero-crimp yarns has been specified. Assuming the sum of yarn diameter and yarn crimp altitude is the same for warp and weft, as this is the case during weaving limp yarns, weave angle and yarn crimp ratio could be expressed in terms of yarn diameters and yarn spacing.

Non-classical methods were introduced [6] to calculate and measure yarn crimp ratio. Woven fabrics could be classified into two types: Floated Weaves and Extended Weaves. In a floated weave, yarn spacing is uniform and equal to yarn spacing at the point of intersection. In an extended weave, yarns are separated only at points of intersection. Simple mathematical models in dimensionless forms were introduced [7]. Yarn crimp ratios in 20 different styles of woven fabrics were measured [11]. Fabric weight was also measured for the same styles.

Fabric weight was calculated using yarn counts, yarn densities, and these measured crimp ratios. Thereafter, fabric weight based on measured yarn crimp ratios was compared with measured fabric weight. There was error in calculated fabric weight, i.e. fabric weight calculated from measured yarn crimp ratio. This error ranges from -4.792 % to 45.067 % [11]. Ten styles out of the twenty styles gave a percentage of error more than 5. This means that the method used for measuring yarn crimp ratio is not accurate and that the degree of inaccuracy differs from one style to another. Accurate measurements or accurate calculations for crimp ratio are required because calculations of yarn consumption and yarn waste are based on it. Not only these calculations, but also the adjustments of let-off, take-up, and picking mechanisms depend on crimp ratios. Weinsdoerfer [8] studied the effect of yarn average float in woven fabric on the value of warp tension on the weaving machine. Yarn average float affects yarn crimp ratio. Yarn crimp ratio affects fabric abrasion resistance, fabric shrinkage, fabric extensibility, crimp interchange between warp and weft after finishing processes, fabric cost, and yarn demand [9].

Because of the importance of maximum set of yarn in the woven fabric, empirical and theoretical relationships relating maximum warp and weft cover factors have been derived, and theoretical relationships have been provided in graphic forms for only simple weaves [10]. Kienbaum [13] defined the relative weaving density as the ratio between actual yarn density and maximum yarn density in the woven fabric. He stated that warp sizing degree, yarn tension during weaving, weave structure, kinetics of beating-up, shed geometry and timing and denting affect yarn density. Weavability limit could be expressed as a function of weave design and yarn diameters [12].

3- Experimental Work (Yarn Diameter Measurement):
This is the practical part required to be achieved as precise as possible and test results are used to facilitate fabric characterization.

3.1- An Outline:
Experimental work is outlined in measuring diameter of each of warp and weft yarns depending on their counts and data obtained from the testing device which is called Hamdy Yarn Diameter Meter (HYDM). This is like a loom but it doesn’t need heald shafts and doesn’t produce a real woven
3.3- Cutting yarn sheet:
Yarn sheet is cut, using a sharp knife, in two corresponding places on the sheet length in order to have complete repeats of corrugated yarn: just under the first cylinder and just after the last one.

3.4- Weighing:
The yarn sheet between the two cutting locations is withdrawn or separated from cylinders and is then weighed. This weight is denoted as W and number of ends in the sheet is denoted as N1.

4- Determining yarn diameter:
The yarn diameter d is determined from the following proven relation:

\[ d = \frac{2000W N_w}{\pi N_1 N_2} - D \]  

\( d \): yarn diameter (mm)
\( D \): cylinder diameter (mm)
\( N_1 \): number of ends in yarn sheet
\( N_2 \): Number of cylinders used for yarn corrugating.
\( N_w \): metric count of yarn (m/g)
\( W \): weight of corrugated yarn sheet (g)

If yarn number T is given in tex (mg/m), the relation will be

\[ d = \frac{2 \times 10^6 W}{\pi N_1 N_2 T} - D \]  

5 - Repeatability – Reproducibility
- Yarn variations (R & R Tool).
The same procedure of preparing yarn sheet, corrugating, cutting, weighing, and calculating is made for each of warp and weft yarns. It can be repeated for the same yarn to check the validity of results.

To verify the applicability of this test method, a ring-spun cotton yarn of Ne 50 i.e. Nm 84.5 was tested. Conditions of the test were as follows:

- Cylinder diameter = 4 mm
- Number of cylinders = 58
- Number of yarns = 25

3.2- Estimating length of yarn sheet:
Length of the part of yarn sheet which is corrugated using cylinders is estimated using the following derived relation:

\[ L = \frac{\pi}{2} N_2 (d + D) \]  

\( L \): length of yarn sheet corrugated around cylinders.
\( d \): yarn diameter (which is required to be measured).
\( D \): cylinder diameter (which is known).
\( N_2 \): number of cylinders used for yarn sheet corrugating.

The yarn sheet length required to carry out the test is taken more than the length \( L \) to permit clamping and corrugating process.
Temperature = 25 °C
Relative Humidity = 73 %
Results of the test are given in Table (1).

### Table (1): Test Results:

<table>
<thead>
<tr>
<th>Weight of corrugated yarn (mg)</th>
<th>Calculated Yarn Diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>110.8</td>
<td>0.11063</td>
</tr>
<tr>
<td>111.7</td>
<td>0.14402</td>
</tr>
<tr>
<td>111.3</td>
<td>0.12918</td>
</tr>
<tr>
<td>109.9</td>
<td>0.07724</td>
</tr>
<tr>
<td>110.7</td>
<td>0.10692</td>
</tr>
<tr>
<td>110.2</td>
<td>0.08837</td>
</tr>
<tr>
<td>111.4</td>
<td>0.13289</td>
</tr>
<tr>
<td>110.5</td>
<td>0.09950</td>
</tr>
<tr>
<td>109.8</td>
<td>0.07353</td>
</tr>
<tr>
<td>111.8</td>
<td>0.14773</td>
</tr>
<tr>
<td>110.1</td>
<td>0.08466</td>
</tr>
<tr>
<td>111.0</td>
<td>0.11805</td>
</tr>
<tr>
<td>110.3</td>
<td>0.09208</td>
</tr>
<tr>
<td>110.0</td>
<td>0.08095</td>
</tr>
<tr>
<td>110.7</td>
<td>0.10692</td>
</tr>
<tr>
<td>110.1</td>
<td>0.08466</td>
</tr>
<tr>
<td>110.9</td>
<td>0.11434</td>
</tr>
<tr>
<td>111.1</td>
<td>0.11063</td>
</tr>
<tr>
<td>111.1</td>
<td>0.12176</td>
</tr>
</tbody>
</table>

Statistical measures of these results are given in Table (2).

### Table (2): Statistical Measures of Test Results:

<table>
<thead>
<tr>
<th>Measure</th>
<th>Weight (mg)</th>
<th>Diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>110.661</td>
<td>0.10544</td>
</tr>
<tr>
<td>Standard Dev.</td>
<td>0.42757</td>
<td>0.02221</td>
</tr>
<tr>
<td>Coeff. of Var. %</td>
<td>0.38638</td>
<td>21.06214</td>
</tr>
</tbody>
</table>

If mean weight is used in calculations, yarn diameter will be 0.105465 mm.

Other known method [2] gave the value of diameter as 0.128 mm assuming yarn density to be 0.916 mg/mm².

Let:
F₁: warp average float
F₂: weft average float
Nₘ₁: warp yarn count (m/g)
Nₘ₂: weft yarn count (m/g)
d₁: warp yarn diameter (mm)
d₂: weft yarn diameter (mm)

### 6- Constraints of Plain and Floatted Woven Fabrics [11]:

#### 6.1- Maximum Weave Angle:

Maximum weave angle for warp and weft can be determined as follows:

\[
\cos \theta_1 = \frac{d_1}{d_1 + d_2}
\]

(3)

\[
\cos \theta_1 = \frac{d_2}{d_1 + d_2}
\]

(4)

θ₁: maximum warp weave angle (degrees)
θ₂: maximum weft weave angle (degrees)

It can be noticed that:

\[
\cos \theta_1 + \cos \theta_2 = 1
\]

(5)

#### 6.2- Maximum Yarn Density (Maximum Yarn Set):

It can be expressed as follows:

\[
n_1 = \frac{10}{\sqrt{d_1^2 + 2d_1d_2}}
\]

(6)

\[
n_2 = \frac{10}{\sqrt{d_2^2 + 2d_1d_2}}
\]

(7)

n₁: maximum warp set (ends/cm)
n₂: maximum weft set (picks/cm)

#### 6.3- Maximum Yarn Crimp Ratio:

\[
C_i = \left[ \frac{\pi(d_1 + d_2)}{180\sqrt{d_1^2 + 2d_1d_2}} \cos^{-1}\frac{d_1}{d_1 + d_2} - \right] / F_i
\]

(8)
\[ C_2 = \left[ \frac{\pi (d_1 + d_2)}{180 \sqrt{d_1^2 + 2d_1d_2}} \cos^{-1} \frac{d_2}{d_1 + d_2} - 1 \right] \sqrt{F_2} \frac{10F_1}{\sqrt{d_2^2 + 2d_1d_2 + (F_1 - 1)d_2}} \]

\[ n_2 = \frac{10F_1}{\sqrt{d_2^2 + 2d_1d_2 + (F_1 - 1)d_2}} \]

(9) \( n_1 \) and \( n_2 \) are overall warp and weft maximum sets.

7.2- Maximum Yarn Crimp Ratio:
\[ C_1 = \frac{\pi (d_1 + d_2) \cos^{-1} \frac{d_1}{d_1 + d_2} + (F_1 - 1)d_2}{\sqrt{d_2^2 + 2d_1d_2 + (F_1 - 1)d_2}} - 1 \]

(18)

\[ C_2 = \frac{\pi (d_1 + d_2) \cos^{-1} \frac{d_2}{d_1 + d_2} + (F_2 - 1)d_1}{\sqrt{d_2^2 + 2d_1d_2 + (F_2 - 1)d_1}} - 1 \]

(19)

7.3- Maximum Yarn Cover Ratio:
\[ K_1 = \frac{F_2 d_1}{d_2} \frac{\sqrt{d_1^2 + 2d_1d_2 + (F_2 - 1)d_1}}{\sqrt{d_1^2 + 2d_1d_2 + (F_2 - 1)d_1}} \]

(20)

\[ K_2 = \frac{F_2 d_1}{d_2} \frac{\sqrt{d_1^2 + 2d_1d_2 + (F_2 - 1)d_1}}{\sqrt{d_1^2 + 2d_1d_2 + (F_2 - 1)d_1}} \]

(21)

7.4- Maximum Cloth Cover Ratio (Kc):
\[ K_c = K_1 + K_2 - K_1 K_2 \]

(22)

K_1 and K_2 are obtained from equations (20) and (21), respectively.

7.5- Maximum Fabric Weight (W_f):
It is calculated from equation (13).

7.6- Fabric Thickness (\( t \)):
It is calculated from equation (14).

7.7- Maximum Fabric Volumetric Density:
It is calculated from equation (15).

8- Details of Actual Woven Fabric:
If a warp with diameter \( d_1 \) and count \( N_{w1} \) is woven with a weft of diameter \( d_2 \) and count \( N_{w2} \) at \( n_1 \) ends/cm and \( n_2 \)
8.1- Weave Angles:
\[
\sin \theta_1 = \frac{10n_2(d_1 + d_2) - n_2d_1\sqrt{100 - n_2^2d_1^2(2d_1 + d_2)^2}}{10 + n_2^2d_1^2}
\]
\[
\sin \theta_2 = \frac{10n_2(d_1 + d_2) - n_1d_2\sqrt{100 - n_2^2d_2^2(2d_1 + d_2)^2}}{10 + n_1^2d_2^2}
\]

8.2- Crimp Ratio:
8.2.1- For Floated Weaves:
\[
C_1 = \left[ \sec \theta_1 - \frac{n_1(d_1 + d_2)}{10}(\tan \theta_1 - \frac{n\theta_1}{180}) \right] \bigg/ \frac{F_1}{F_2}
\]
\[
C_2 = \left[ \sec \theta_2 - \frac{n_2(d_1 + d_2)}{10}(\tan \theta_2 - \frac{n\theta_2}{180}) \right] \bigg/ \frac{F_2}{F_1}
\]

8.2.2- For Extended Weaves:
\[
C_1 \text{ obtained from equation (25) must be multiplied by } \left[ F_1 - \frac{n_2^2d_1^2}{10}(F_1 - 1) \right]
\]
\[
C_2 \text{ obtained from equation (26) must be multiplied by } \left[ F_2 - \frac{n_2d_1}{10}(F_2 - 1) \right]
\]

8.3- Yarn Cover Ratio:
\[
K_1 = \frac{n_1d_1}{10}
\]
\[
K_2 = \frac{n_2d_1}{10}
\]

8.4- Cloth Cover Ratio:
\[
K_3 = \frac{n_1d_1 + n_2d_2}{10} - \frac{n_1n_2d_1d_2}{100}
\]

8.5- Fabric Weight: [Equation (13)]

8.6- Fabric Thickness: [Equation (14)]
10- Maximum Tightness of Extended Weaves:

10.1- Maximum Warp Tightness (weft intersections /cm of fabric width):

\[ T_{\text{wa}} = \frac{10}{\sqrt{d_1^2 + 2d_1d_2 + (F_1 - 1)d_2}} \]  

(36)

10.2- Maximum Weft Tightness (warp intersections /cm of fabric length):

\[ T_{\text{w}} = \frac{10}{\sqrt{d_2^2 + 2d_1d_2 + (F_1 - 1)d_2}} \]  

(37)

11- Conclusions:

From this work it is noticed that single woven fabrics can be objectively characterized either through or extended and the measuring yarn diameters by an accurate method (HYDM) is the most important step in estimating fabric parameters. Replacing thickness measuring by weight measuring interprets this accuracy. Moreover, the measured value can be considered as an average of a number of locations on the yarn equal to number of cylinders multiplied by number of yarn end in the prepared sheet. These locations are distributed regularly on the yarn sheet. Yarn diameter measured by this accurate method helps estimate many constructional details in the woven fabrics. It helps estimate the maximum angle of inclination yarn can make with fabric plane when it changes its position from one fabric side to the other i.e. maximum weave angle. It helps also estimate the minimum yarn spacing, and the maximum yarn density in the woven fabric i.e. yarn weavability. As fabric is made to cover, yarn and fabric maximum covering powers must be known. This could be expressed in terms of yarn diameters. Weave structure (represented by yarn average float and weave class) is used with yarn diameters to determine maximum yarn crimp ratio. Maximum fabric weight can be estimated from yarn diameters, yarn average floats, and yarn counts. Only yarn diameters are needed to estimate fabric thickness. Maximum fabric volumetric density can be predicted depending on yarn diameters, weave structure, and yarn counts.

These previously mentioned data are the boundaries of the fabric woven from certain yarns according to a certain weave structure. For the fabric to be woven and for which yarn densities are far enough from estimated maximum yarn densities according to yarn properties and weaving machine possibilities, many useful data can be presented. Fabric thickness can be simply estimated as the sum of warp and weft diameters. In terms of yarn diameters and densities, weave angles and yarn and fabric cover ratios can be calculated. Adding weave structure to yarn diameters and densities enables estimating actual yarn crimp ratios. Fabric weight and volumetric density can be estimated knowing the previous data. Relative weaving density can be determined from actual yarn density and maximum yarn density. Tightness of warp and weft can be expressed in terms of yarn diameter and average float.

References:


