SINGLE WOVEN FABRIC CHARACTERIZATION IN TERMS OF YARN DIAMETER AND AVERAGE FLOAT "THEORETICAL CONSIDERATIONS AND TEST RESULTS"

توصيف القماش المنسوج الأحادى بدلالة قطر الخيط ومتوسط التشييف "إعتبارات نظرية ونتائج اختبار"

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خلاصة:

يقدم هذا البحث طريقة عملية دقيقة لقياس قطر الخيط وطريقة نظرية مبنية على أساس علمي، وفى نفس الوقت، سهلة، وبسيطة، وغير مكلفة، لتوصيف الخواص الهندسية، والتفاصيل الإنشائية، للقماش المنسوج الأحادى. وقد تم التوصل إلى جميع الصيغ والمعادلات بالإستنتاج والإثبات. وفى هذا البحث أمكن تصنيف الأقمشة المنسوجة الأحادية إلى نوعين: المشيف، والممتد. ويتميز الأول بانتظام المسافة بين كل خيطين متجاورين فى القماش، بينما يتميز الثانى بعكس ذلك. واستخدم متوسط التشييف- بناء على التحليل النظرى- للتعبير عن التركيب النسجى. وقد أمكن استخدام قطر الخيط، وطريقة التعاشق لكل من السداء واللحمة فى إيجاد حد النسيج لكل منهما (أقصى كثافة). وعند كل كثافة ونمرة للخيوط أمكن التنبؤ بخواص نسبة التشريب، ونسبة التغطية، وسمك ووزن وكثافة القماش وكذلك الكثافة النسبية للخيوط كمقياس لدرجة صعوبة النسيج. وتتضمن درجة إحكام القماش درجة إحكام السداء (عدد تعاشقات اللحمة/ وحدة عرض من القماش)، ودرجة إحكام اللحمة (عدد تعاشقات السداء/ وحدة طول من القماش). وعدد تعاشقات اللحمة/ وحدة عرض من القماش يساوى كثافة السداء مقسومة على متوسط تشييف اللحمة. وعدد تعاشقات السداء/ وحدة طول من القماش يساوى كثافة اللحمة مقسومة على متوسط تشييف السداء. وقد أمكن التعبير عن درجة الإحكام القصوى بدلالة قطر الخيط ومتوسط التشييف. وقد تم اشتقاق جميع الصيغ باستخدام المبادىء الأولية، كما تم تعديل نموذج بيرس للأقمشة المنسوجة بحيث يمكن فرد القماش على سطح مستو ليتلامس معه بكل خيوطه. ويساعد البحث فى اختيار نوع ماكينة النسيج المناسبة لكل صنف من القماش حسب بياناته الإنشائية وإيجاد بديل عن بعض الأجهزة المستخدمة فى إختبار الأقمشة.

Abstract:

This research work presents an accurate experimental method for measuring yarn diameter and a theoretical method based on a scientific basis and, in the same time, easy, simple, and not costly with respect to cash, labor, or raw materials, to characterize the geometrical properties and constructional details of the single woven fabric. All formulae and equations are obtained by derivation and prooving. Single woven fabrics could be classified into two types: *Floated* and *Extended*. *Floated weaves* are characterized by regular yarn spacing, whereas *Extended weaves* are characterized by irregular yarn spacing. Average float was used, building on the theoretical analysis, to express the weave structure. Yarn diameter and interlacing method for each of warp and weft are important constructional details used to calculate maximum density of yarns in the fabric i.e. yarn weavability. Yarn densities are used besides these details in predicting yarn crimp ratio, yarn cover ratio, fabric cover ratio, and fabric thickness. Assuming maximum set of yarns in the fabric, according to the values predicted, maximum yarn crimp ratio, and maximum yarn and fabric cover ratios can be calculated. Fabric tightness comprises warp tightness (weft intersections/ unit fabric width) and weft tightness (warp intersections/ unit fabric length). Warp intersections/ unit fabric length equals picks/ cm divided by warp average float, and Weft intersections/ unit fabric width equals ends/ cm divided by weft average float. Maximum tightness could be expressed in terms of yarn diameter and average float. Using yarn count in addition to the above mentioned details, fabric weight can be determined either at maximum yarn density (maximum weight) or at normal yarn densities (normal weight). Fabric thickness is determined in terms of yarn diameters. Yarn volumetric density is determined in terms of yarn diameter and count.

Accepted June 30, 2009.

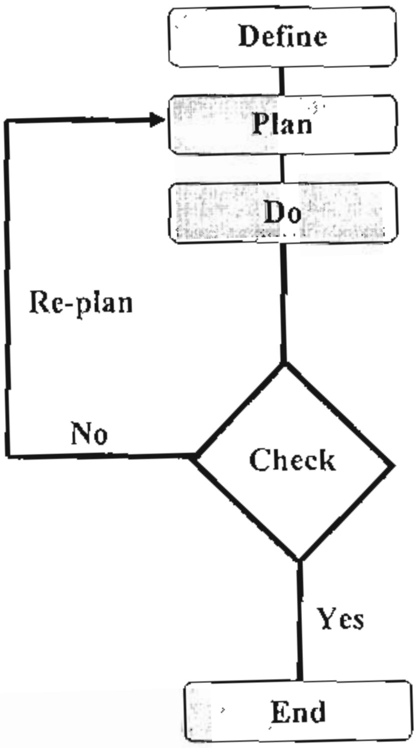
Knowing fabric weight and thickness enables calculating its volumetric density. The relative weaving density (the ratio between actual yarn density and maximum yarn density) can also be calculated. All expressions are derived using elementary principles. Peirce's model of woven fabrics is modified in such a manner that fabric can be spread onto a planer 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 fabric. It is used to *corrugate* a yarn *sheet* by inserting *cylinders* through it. Yarns represent warp and *cylinders* represent weft. There is no need to a beat-up mechanism as *cylinders* are put by hand one after the other on the warp sheet in such a manner that one *cylinder* is put in one side of the sheet and the next is put in the other side. *Cylinders* are laid in one plane. This plane is made inclined to avoid yarn distortion or flattening due to *cylinder* weight. To achieve the same purpose *cylinders* are chosen light and when their diameter is relatively great they may be made hollow in order to be as light as possible. This test is carried out on a sheet of warp yarn and a sheet of weft yarn to determine warp and weft diameters, respectively. Yarn sheet is made by unwinding yarn from its package and winding it onto a hand or a motorized reel equipped with a helical traversing shaft to distribute yarn layers uniformly across the sheet. The length of creel circumference is chosen to suit the length of yarn sheet required for the test.

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:

$$L = \frac{\pi}{2} N_2 (d + D) \qquad (1)$$

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.

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 N_1.

4- Determining yarn diameter:

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

$$d = \frac{2000W\,N_m^{\prime}}{\pi N_1 N_2} - D \qquad (2)$$

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_m: 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

$$d = \frac{2 * 10^6 W}{\pi N_1 N_2 T} - D \qquad (2^*)$$

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

Temperature = 25 °C
Relative Humidity =73 %.
Results of the test are given in Table (1).

Table (1): Test Results:

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

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

Table (2): Statistical Measures of Test Results:

Measure	Weight (mg)	Diameter (mm)
Mean	110.661	0.10544
Standard Dev.	0.42757	0.02221
Coeff. of Var. %	0.38638	21.06214

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/mm^3.

. Let:
F_1: warp average float
F_2: weft average float
N_{m1}: warp yarn count (m/g)
N_{m2}: weft yarn count (m/g)
d_1: warp yarn diameter (mm)
d_2: weft yarn diameter (mm)

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

6.1- Maximum Weave Angle:

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

$$\cos\theta_1 = \frac{d_1}{d_1 + d_2} \tag{3}$$

$$\cos\theta_2 = \frac{d_2}{d_1 + d_2} \tag{4}$$

θ_1: maximum warp weave angle (degrees)
θ_2: maximum weft weave angle (degrees)
It can be noticed that:

$$\cos\theta_1 + \cos\theta_2 = 1 \tag{5}$$

6.2- Maximum Yarn Density (Maximum Yarn Set):

It can be expressed as follows:

$$n_1 = \frac{10}{\sqrt{d_1^2 + 2d_1d_2}} \tag{6}$$

$$n_2 = \frac{10}{\sqrt{d_2^2 + 2d_1d_2}} \tag{7}$$

n_1: maximum warp set (ends/cm)

n_2: maximum weft set (picks/cm)

6.3- Maximum Yarn Crimp Ratio:

$$C_1 = \left[\frac{\pi(d_1 + d_2)}{180\sqrt{d_2^2 + 2d_1d_2}}\cos^{-1}\frac{d_1}{d_1 + d_2} - 1\right] / F_1 \tag{8}$$

$$C_2 = \left[\frac{\pi(d_1+d_2)}{180\sqrt{d_1^2+2d_1d_2}}\cos^{-1}\frac{d_2}{d_1+d_2} - 1\right]/F_2 \qquad (9)$$

C_1: maximum warp crimp ratio

F_1: average warp float (F_1=1 in plain woven fabric)

C_2: maximum weft crimp ratio

F_2: average weft float (F_2=1 in plain woven fabric)

6.4- Maximum Yarn Cover Ratio:

$$K_1 = \frac{d_1}{\sqrt{d_1^2+2d_1d_2}} \qquad (10)$$

$$K_2 = \frac{d_2}{\sqrt{d_2^2+2d_1d_2}} \qquad (11)$$

K_1: maximum warp cover ratio

K_2: maximum weft cover ratio

6.5- Maximum Cloth Cover Ratio (K_c):

$$K_c = \frac{d_1}{\sqrt{d_1^2+2d_1d_2}} + \frac{d_2}{\sqrt{d_2^2+2d_1d_2}} - \frac{d_1d_2}{\sqrt{2d_1^3d_2+5d_1^2d_2^2+2d_1d_2^3}} \qquad (12)$$

6.6- Maximum Fabric Weight (W_f):

$$W_f = \frac{100n_1(1+C_1)}{N_{m1}} + \frac{100n_2(1+C_2)}{N_{m2}} \qquad (13)$$

W_f: maximum fabric weight (g/m^2)

5.7- Fabric Thickness (t):

$$t = d_1 + d_2 \qquad (14)$$

6.8- Maximum Fabric Volumetric Density (g/cm^3):

$$\rho_f = \frac{n_1(1+C_1)}{10N_{m1}(d_1+d_2)} + \frac{n_2(1+C_2)}{10N_{m2}(d_1+d_2)} \qquad (15)$$

7- Constraints of Extended Woven Fabric [12]:

7.1- Maximum Yarn Density (Maximum Set):

$$n_1 = \frac{10F_2}{\sqrt{d_1^2+2d_1d_2}+(F_2-1)d_1} \qquad (16)$$

$$n_2 = \frac{10F_1}{\sqrt{d_2^2+2d_1d_2}+(F_1-1)d_2} \qquad (17)$$

n_1 and n_2 are overall warp and weft maximum sets.

7.2- Maximum Yarn Crimp Ratio:

$$C_1 = \frac{\frac{\pi}{180}(d_1+d_2)\cos^{-1}\frac{d_1}{d_1+d_2}+(F_1-1)d_2}{\sqrt{d_2^2+2d_1d_2}+(F_1-1)d_2} - 1 \qquad (18)$$

$$C_2 = \frac{\frac{\pi}{180}(d_1+d_2)\cos^{-1}\frac{d_2}{d_1+d_2}+(F_2-1)d_1}{\sqrt{d_1^2+2d_1d_2}+(F_2-1)d_1} - 1 \qquad (19)$$

7.3- Maximum Yarn Cover Ratio:

$$K_1 = \frac{F_2d_1}{\sqrt{d_1^2+2d_1d_2}+(F_2-1)d_1} \qquad (20)$$

$$K_2 = \frac{F_1d_2}{\sqrt{d_2^2+2d_1d_2}+(F_1-1)d_2} \qquad (21)$$

7.4- Maximum Cloth Cover Ratio (K_c):

$$K_c = K_1 + K_2 - K_1K_2 \qquad (22)$$

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_{m1} is woven with a weft of diameter d_2 and count N_{m2} at n_1 ends/cm and n_2

picks per cm such that warp average float is F_1 and weft average float is F_2, the following expressions [5 & 6] are used to specify fabric details:

8.1- Weave Angles :

$$\sin\theta_1 = \frac{10n_2(d_1+d_2) - n_2 d_1\sqrt{100 - n_2^2 d_2(2d_1+d_2)}}{100 + n_2^2 d_1^2} \quad (23)$$

$$\sin\theta_2 = \frac{10n_1(d_1+d_2) - n_1 d_2\sqrt{100 - n_1^2 d_1(2d_2+d_1)}}{100 + n_1^2 d_2^2} \quad (24)$$

8.2- Crimp Ratio:

8.2.1- For Floated Weaves:

$$C_1 = \left[\sec\theta_1 - \frac{n_2(d_1+d_2)}{10}\left(\tan\theta_1 - \frac{\pi\theta_1}{180}\right) - 1\right] / F_1 \quad (25)$$

$$C_2 = \left[\sec\theta_2 - \frac{n_1(d_1+d_2)}{10}\left(\tan\theta_2 - \frac{\pi\theta_2}{180}\right) - 1\right] / F_2 \quad (26)$$

8.2.2- For Extended Weaves:

C_1 obtained from equation (25) must be multiplied by $\left[F_1 - \frac{n_2 d_2}{10}(F_1 - 1)\right]$

and C_2 obtained from equation (26) must be multiplied by $\left[F_2 - \frac{n_1 d_1}{10}(F_2 - 1)\right]$.

8.3- Yarn Cover Ratio:

$$K_1 = \frac{n_1 d_1}{10} \quad (27)$$

$$K_2 = \frac{n_2 d_2}{10} \quad (28)$$

8.4- Cloth Cover Ratio:

$$K_c = \frac{n_1 d_1}{10} + \frac{n_2 d_2}{10} - \frac{n_1 n_2 d_1 d_2}{100} \quad (29)$$

8.5- Fabric Weight: [Equation (13)]

8.6- Fabric Thickness: [Equation (14)]

8.7- Fabric Volumetric Density:
[Equation (15)]

8.8- Relative Weaving Density (the ratio between actual yarn density and maximum yarn density in the woven fabric):

8.8.1- Plain and Floated Weaves:

For warp

$$n_{r1} = \frac{n_1\sqrt{d_1^2 + 2d_1 d_2}}{10} \quad (30)$$

and for weft

$$n_{r2} = \frac{n_2\sqrt{d_2^2 + 2d_1 d_2}}{10} \quad (31)$$

8.8.2- Extended Weaves:

For warp

$$n_{r1} = \frac{n_1\left[\sqrt{d_1^2 + 2d_1 d_2} + (F_2 - 1)d_1\right]}{10F_2} \quad (32)$$

and for weft

$$n_{r2} = \frac{n_2\left[\sqrt{d_2^2 + 2d_1 d_2} + (F_1 - 1)d_2\right]}{10F_1} \quad (33)$$

9- Maximum Tightness of Plain and Floated Weaves:

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

$$T_{1m} = \frac{10}{F_2\sqrt{d_1^2 + 2d_1 d_2}} \quad (34)$$

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

$$T_{2m} = \frac{10}{F_1\sqrt{d_2^2 + 2d_1 d_2}} \quad (35)$$

10- Maximum Tightness of Extended Weaves:

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

$$T_{1m} = \frac{10}{\sqrt{d_1^{\,2} + 2d_1d_2 + (F_2 - 1)d_1}} \quad (36)$$

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

$$T_{2m} = \frac{10}{\sqrt{d_2^{\,2} + 2d_1d_2 + (F_1 - 1)d_2}} \quad (37)$$

11- Conclusions:

From this work it is noticed that single woven fabrics can be objectively characterized either floated or extended and that measuring yarn diameter 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 ends 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.

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