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USING WEIGHING AND COUNTING IN MEASURING YARN DIAMETER
&
DETERMINING YARN VOLUMETRIC DENSITY

إستخدام الوزن والعد في قياس قطر الخيط وتحديد الكثافة الحجمية له

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خلاصة:

يقدم البحث طريقة علمية دقيقة وسريعة لقياس قطر الخيط تعتمد على أسس رياضية خالصة دون أى تقريب، حيث يتم إعداد الخيط في صورة خطوط متوازية وموزعة بانتظام، وتتسج هذه الأجزاء (كسداء) مع أسلاك متوازية لها قطاع ثابت (كلحات)، بحيث تقع هذه الأسطوانات في مستوى واحد وتصل إلى حالة الإزدحام النهائي. ويكون أسلوب التعاشق كما في النسيج السادة، وبمعلومية عدد أجزاء الخيط، وعدد الأسطوانات، وقطر الأسطوانة، ووزن أجزاء الخيوط المتعاشقة مع الأسطوانات، ونمرة الخيط، أمكن إيجاد كل من قطر الخيط، وكثافته الحجمية بالتعويض في علاقتين تم إيجادهما. ويقدم البحث شرحاً للجهاز المستخدم في عملية تشكيل أجزاء الخيط إلى تكوين نسجي.

ABSTRACT:

A scientific, accurate, and rapid method is presented to measure yarn diameter. This method is built on pure mathematical bases without any approximation. A small sheet of parallel and equi-spaced ends is made from the yarn to be tested. Then this sheet is woven manually (as warp) with straight light wires of identical circular cross-section (as weft) in such a manner that wires reach the jamming condition and the interlacing is according to the method of plain weave. Results obtained from this prepared test specimen are number of yarn ends woven as warp, number of wires woven as weft, wire diameter, and weight of yarn interlaced with wires. For the tested yarn, only its count is required. Substituting for these five values in two simple derived formulae yarn diameter and yarn volumetric density can be obtained. The device used to perform the test is indicated.

1- INTRODUCTION:

Yarn diameter is the most important geometrical property upon which adjustments in production lines depend. It was used to determine maximum set of woven fabrics. Maximum woven fabric construction theories were built on yarn diameter [1]. Peirce [2] built his maximum weavability formula for plain weave cotton fabrics on the ratio of weft diameter to warp diameter. Kienbaum [3] expressed minimum yarn spacing and maximum yarn density in woven fabric in terms of warp and weft yarn diameters. He calculated yarn diameter assuming yarn density. Chen [4] used yarn diameter in expressing fabric cover factor to make an engineering design of woven fabric. He used the sum of warp and weft diameters in his formulae for fabric shear and bending moduli.

Because yarn is made of viscoelastic fine materials (fibres), because its structure is loose and its surface is often hairy, and because it is compressible, no one has thought of measuring its diameter by methods like those used for metals or other relatively more rigid materials. Trials have been made to magnify the yarn and measure its shadow. Yarn thickness without external constraints is measured (optical method) by

Shirley Yarn Diameter Projector [5]. The problem is in defusing the yarn surface. Yarn thickness is measured (photoelectrically) by Chamberlain Apparatus. The problem is that the apparatus still has to be calibrated by reference to the more direct method of shape or boundaries observation. Other trials have been made to put suggested formulae and expressions to estimate the diameter of the yarn [6]. Ashenhurst [6] determined empirically a constant for every kind of yarn to use it with linear density to estimate yarn diameter. For the same purpose Peirce [2] derived a formula for cotton yarn diameter as a function of its count assuming its specific volume as $1.1 \text{ cm}^3/\text{g}$. This value was the minimum cotton yarn specific volume. It was obtained by measuring yarn diameter while the yarn is pressed from all sides i.e. while the yarn is highly twisted [5]. Boundaries of a highly twisted yarn were easy to locate, so micrometer methods could be used. Oxley [7] passed cotton yarns between two polished steel surfaces under a load of 70 g. The coarse relatively soft-twisted places were flattened easily (and gave low readings) while the fine hard-twisted places tended to retain their cylindrical form (and gave high readings). The quantity measured was therefore compressibility rather than thickness. Yarn shape was presented and yarn appearance was simulated [8] using computer aided geometric design techniques. There was another problem in estimating yarn diameter mathematically. This problem was the need to know the yarn volumetric density which depends not only on fibre volumetric density but also on yarn structure. Fibre volumetric density is difficult to be measured and yarn structure is difficult to be assessed towards determining the yarn volumetric density. Many instruments have been built and developed to measure yarn count or linear density and many systems have been introduced to suit for different yarn sizes. To get yarn count we must take account of moisture (which affects the weight). Yarn length measuring is sensitive to tension. It can not be measured at zero tension, therefore tension must be standardized.

From this introduction it can be concluded that subjective judgment on yarn boundaries, yarn compression or flattening, and yarn length measurement must be avoided. These three requirements are carried out in this work. The philosophy behind this test method is that as yarn sheet is wrapped or lapped around wires one by one, and as yarn is laid without applying any tension to it, there will be no chance for yarn migration from one wire to the next. Moreover, if yarn is flattened at nipping points between wires, yarn migration will be local i.e. on the wire on which it wraps. This is due to yarn flexibility. Therefore, length of yarn woven with wires will not be affected by yarn flattening if it occurred.

2- SCIENTIFIC BASIS:

Based on Peirce's Flexible Model of woven fabric [2] and on the theoretical study of woven fabric geometry [9 & 10], warp crimp ratio in a woven fabric with zero-crimp jammed weft is expressed as follows:

$$C_1 = \frac{\pi D}{P_2} - 1 \quad (1)$$

C_1 : warp crimp ratio

$$D = (d_1 + d_2)/2 \quad (2)$$

d_1 : warp yarn diameter [mm]

d_2 : weft yarn diameter [mm]

P_2 : weft yarn spacing [mm]

Based on the formula in equation (1) a new experimental method for measuring yarn crimp ratio in woven fabrics [11] gave the following formula:

$$C = \frac{WN_m}{NL_c} - 1 \quad (3)$$

C : yarn crimp ratio

L_c : yarn crimped length [mm]

N : number of unravelled yarns

N_m : metric count of unravelled yarn [mm/mg]

W : weight of unravelled yarns [mg]

Applying the formula (3) to warp by adding the subscript 1 to the symbols

$$\therefore C_1 = \frac{W_1 N_{m1}}{N_1 L_{c1}} - 1 \quad (4)$$

From equations (1), (2), and (4)

$$\therefore \frac{\pi(d_1 + d_2)}{2P_2} = \frac{W_1 N_{m1}}{N_1 L_{c1}} \quad (5)$$

$$\text{But } N_2 = \frac{L_{c1}}{P_2} \quad (6)$$

N_2 : number of weft yarns in the test specimen.

From (5) and (6)

$$\therefore d_1 = \frac{2W_1 N_{m1}}{\pi N_1 N_2} - d_2 \quad (7)$$

Equation (7) states that for a fabric woven from normal warp ends but with zero-crimp weft at maximum sett (maximum weft density) and maximum frequency of interlacing (plain weave) the warp yarn diameter d_1 (mm) could be expressed as a function of:

- i) weight of warp threads only (W_1) [mg]
- ii) metric count of warp (N_m) [mm/mg]
- iii) number of warp ends weighed (N_1)
- iv) number of weft threads woven (N_2)
- v) diameter of weft thread (d_2) [mm]

From yarn diameter and yarn count yarn volumetric density ρ_1 (mg/mm^3) can be determined as follows:

$$\rho_1 = \frac{4}{\pi N_m d_1^2} \quad (8)$$

Substituting from (7) in (8)

$$\therefore \rho_1 = \frac{4}{\pi N_m \left[\frac{2W_1 N_{m1}}{\pi N_1 N_2} - d_2 \right]^2} \quad (9)$$

As specific volume is the reciprocal of volumetric density, yarn specific volume is determined from the following equation:

$$v_1 = \frac{\pi N_m \left[\frac{2W_1 N_{m1}}{\pi N_1 N_2} - d_2 \right]^2}{4} \quad (10)$$

v_1 is yarn specific volume (mm^3/mg).

The length (mm) of yarn sheet interlaced as warp with wires as weft is related to wire diameter, yarn diameter, and number of wires according to the following formula:

$$L_{w1} = \frac{\pi}{2} N_2 (d_1 + d_2) \quad (11)$$

The length (mm) of yarn woven with wires is given from the following relation:

$$L_w = \frac{\pi}{2} N_1 N_2 (d_1 + d_2) \quad (12)$$

If width of clamp which guides yarn sheet during interlacing process is b (mm), then the length (mm) of test specimen (prepared warp sheet) will be

$$L_s \geq L_{w1} + 2b \quad (13)$$

$$\text{or } L_s \geq \frac{\pi}{2} N_2 (d_1 + d_2) + 2b \quad (14)$$

Fig. (1) shows a sketch of one pair of clamps.

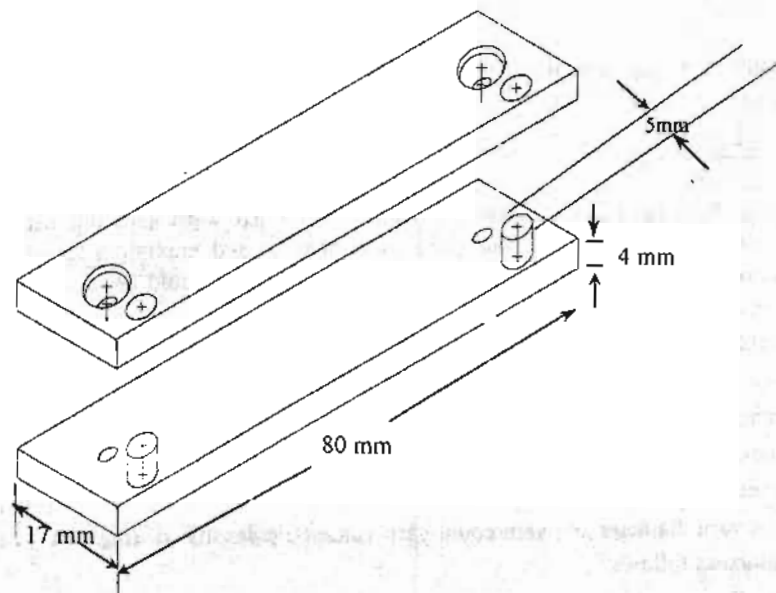


Fig. (1): A sketch of one pair of clamps.

Length (mm) of yarn required to make one test (N_1 yarn segments of unknown diameter d_1 interlaced with N_2 wires of known diameter d_2 and clamped by two pairs of clamps each of width b) will be

$$L_y \geq \frac{\pi}{2} N_1 N_2 (d_1 + d_2) + 2N_1 b \quad (15)$$

Weight (mg) of corrugated yarn is expressed as follows:

$$W_1 = \frac{\pi N_1 N_2}{2 N_m} (d_1 + d_2) \quad (16)$$

3- HOW TO USE THESE EQUATIONS:

Now it can be said that to know the yarn diameter, it is required to weave it (as a warp) with zero-crimp weft threads, bars, or wires according to the rule of plain weave and at the maximum set of weft. In other words, the conditions are maximum warp interlacing (**plain weave**), **maximum** weft density (jamming condition), and minimum weft crimp (**zero-crimp**). Then the conditions of the model described by equation (7) are reached, and it is then ready to determine the diameter of warp yarn. It is worth saying that **warp yarns are not necessarily** woven in an alternative order as for every two adjacent yarns in plain weave repeat, but all the warp ends can interlace similarly with weft threads to achieve the previously mentioned conditions. It is only required that every warp end passes over a weft thread and then under the next, and so on. In this case the warp repeat will be on one end and, therefore, the number of ends can be either odd or even. The number of weft threads is not also necessarily even.

4- HOW TO INCREASE THE ACCURACY OF CALCULATION IN EQUATIONS [(7), (9), AND (10)]:

Here we deal with a small distance (d_1). The value of d_1 is equal to the difference between two values as shown in equation (7). To increase the accuracy of calculation, the second value (d_2) must be chosen as big as possible. This will be accompanied by increasing the first value ($\frac{2W_1 N_{m1}}{\pi N_1 N_2}$). This trend must not be on the account of deforming warp ends. This means that the weft threads must be as light as possible to avoid deforming or flattening of warp ends. The value W_1 can be increased by increasing N_1 , N_2 , d_2 , or any combination of them. Increasing the number of warp ends / unit space helps improve the accuracy by reducing warp yarn deformation. An example for yarn distribution on one wire is shown in Fig. (2).

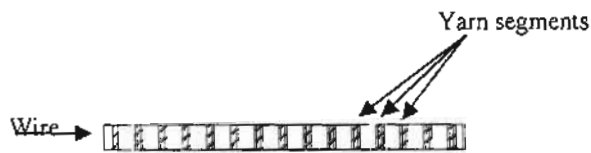


Fig. (2): Distribution of Yarn Ends on Wire Surface

Yarn diameter is measured as an average of $N_1 N_2$ values along a length of yarn equal to $\frac{\pi}{2} N_1 N_2 (d_1 + d_2)$. Therefore the accuracy comes from increasing number of yarn segments (ends), number of wires, and wire diameter.

5- BUILT DEVICE:

A device equipped with a number of circular light rigid straight wires of different diameters is built. Wires may be made hollow to reduce their weight if necessary. Wire diameters chosen are 4, 5, 6, 8, 10, and 12 mm to be suitable for fine and coarse yarns (small diameters for fine yarns, and vice versa). The device consists of two slotted straight bars connected by a back plate to give a working distance of 63 mm between the two slots which are facing each other. The two ends of each wire are

made cylindrical with a radius of 4 mm and a minimum clearance is allowed in the slot width to facilitate inserting wires. Length of wire end is equal to the slot depth with a small play. This play facilitates inserting wires one after the other during yarn corrugating. A base plate 61 mm wide is mounted to the back plate. This base plate will carry the yarn-wire assembly. Two warp sheet clamps of length 80 mm are also needed. The instrument is equipped with more similar clamps to facilitate preparing more than one warp sheet from the same yarn package at the same time. The bar frame occupies a space of 500 mm x 100 mm x 52 mm. A sketch of the device is shown in Fig. (3).

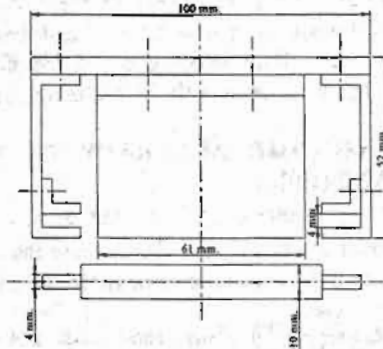


Fig. (3): A sketch of the device (a plan view) indicating the two vertical 4-mm slots, the 61-mm wide base plate, and one 10-mm diameter cylinder drawn separately

An isometric of the device is shown in Fig. (4).



Fig. (4): An Isometric of Interlacing Device

A small hand-operated reel (200-mm diameter) with a small-pitch screw is used to traverse the yarn when it is unwound from the yarn package and wound onto the yarn reel. Screws of different small pitches can be provided to suit different yarn sizes and to traverse every yarn as slowly as possible to have a high yarn density in the yarn sheet.

6- HOW TO CARRY OUT THE TEST:

6-1- Preparing Yarn Sheet:

Yarn sheet is prepared using the hand-operated reel with the suitable screw in such a manner that the sheet width doesn't exceed the distance between the slotted bars (60

mm). The length of one turn on the reel (reel circumference) will be about 628 mm. Two warp sheets are made from the yarn on the reel. Two clamps (next to each other) clamp the sheet in one position on the reel circumference and two other clamps clamp it in an opposite position. The sheet is cut between each pair of clamps. This gives two test specimens. If a more number of test specimens is to be made from one reeling operation, reel circumference will be equally divided by an equal number of clamp pairs.

6-2- Weaving Yarn Sheet as a Warp Yarn with Wires as Weft:

We have now two yarn sheets each of which is clamped at its two ends. Yarn segments are parallel and equi-spaced. This allows us to measure the yarn diameter twice. The bar frame is tilted to be inclined at a suitable angle to the vertical and is then fixed in this position. One clamp is put onto the instrument base between the slotted bars and yarn sheet is straightened onto the base plate. One wire is put on yarn sheet after passing through the two slots. The whole warp sheet is made to cover this wire by moving the free clamp to the other side of the bar frame. The second wire is inserted like the first one. The warp sheet is moved by the free clamp to the other side of the frame, and so on. Interlacing process is shown in Fig. (5).

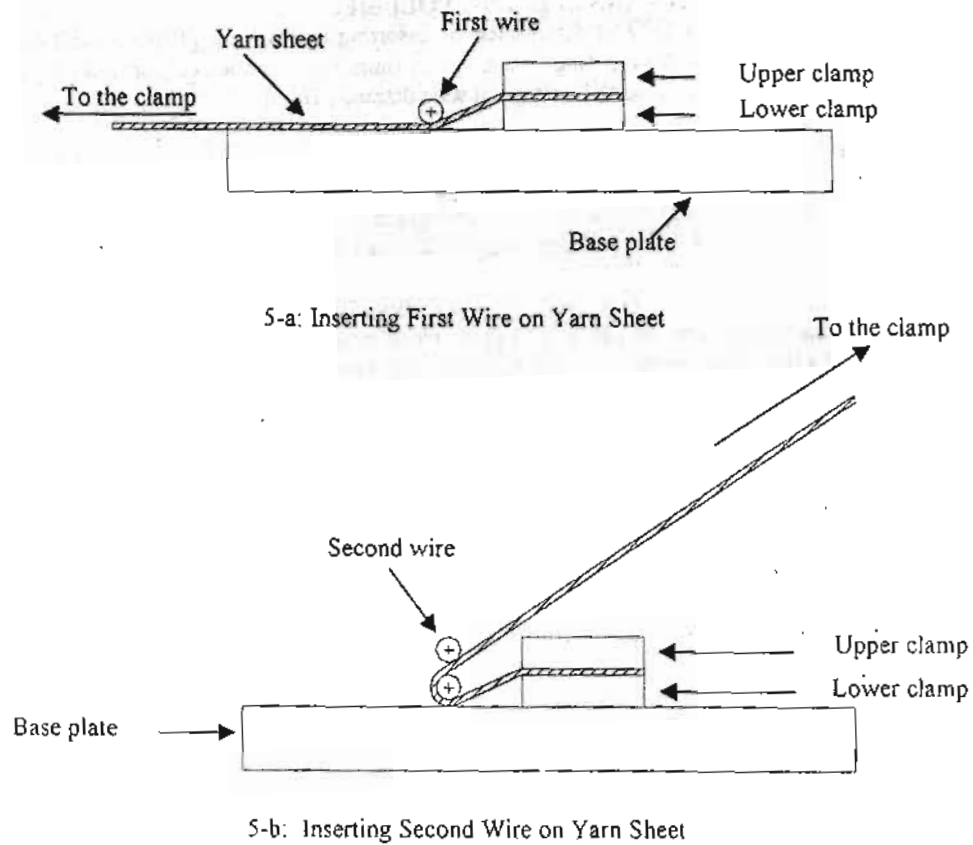


Fig. (5): Interlacing Process

6-3- Cutting Corrugated Warp Sheet:

After a suitable number of typical wires are inserted through the warp sheet, yarn sheet is cut in two corresponding places: just under the first wire and just over the last one in such a manner that complete lapping repeats of yarn around wires are obtained. Complete lapping repeat is a semi-circle i.e. an arc subtending a central angle of 180° . Cutting is performed using a sharp cutter.

6-4- Weighing and Counting:

The warp sheet between the two cutting places is removed and then weighed to the nearest 0.1 mg. Number of yarn ends and number of wires woven are registered.

7- DETERMINING YARN DIAMETER:

Yarn diameter is determined by inserting in equation (7) the values for weight of corrugated yarn (mg), yarn count (mm/mg), number of corrugated yarn segments, number of inserted wires, and wire diameter (mm).

8- DETERMINING YARN VOLUMETRIC DENSITY:

Yarn volumetric density is determined by inserting in equation (9) the values for weight of corrugated yarn (mg), yarn count (mm/mg), number of corrugated yarn segments, number of inserted wires, and wire diameter (mm).

9- DETERMINING YARN SPECIFIC VOLUME:

Yarn specific volume is determined by inserting in equation (10) the values for weight of corrugated yarn (mg), yarn count (mm/mg), number of corrugated yarn segments, number of inserted wires, and wire diameter (mm).

10- BALANCE CAPACITY:

If yarn diameter is 0.1 mm, yarn count is 169 m/g (or 169 mm/mg), wire diameter is 4 mm, number of yarn segments is 300 (yarn cover ratio is 0.5), and number of wires is 10, then the approximate weight obtained from the balance will be 114.32 mg.

If yarn diameter is 2 mm, yarn count is 1 m/g (or 1 mm/mg), wire diameter is 12 mm, number of yarn segments is 15 (yarn cover ratio is 0.5), and number of wires is 20, then the approximate weight obtained from the balance will be 6597.34 mg.

These two extreme values of corrugated yarn weight are obtained by inserting in equation (7). A balance which has a capacity of 10 g or more and measures to the nearest 0.1 mg (4 decimal positions of gramme) is selected.

11- REDUCING YARN WASTE:

For the two extreme cases described above, length of yarn woven with wires is approximately 19320 mm and 6597 mm, respectively. This is obtained by inserting in equation (12). If clamp width is 10 mm, length of yarn in clamping zones is 6000 mm and 300 mm, respectively. Minimum yarn length required to make one test is approximately 25320 mm and 6897 mm, respectively. Minimum length of warp sheet is 85 mm and 460 mm, respectively. If reel circumference is 600 mm, then one reeling operation will be enough for 7 samples and 1 sample, respectively. In case of fine yarns and soft yarns it is preferred to reduce the number of wires. In case of coarse yarns and hard yarns it is preferred to increase the number of wires. In all cases yarn cover ratio must be as high as possible, but not more than 1.

12- ANGLE OF INCLINATION OF BAR FRAME TO THE VERTICAL:

This angle is increased in the case of soft and limp yarns to avoid yarn flattening and because the yarn turns easily round wires, respectively. It is reduced in the case of hard and stiff yarns but to the extent which avoids yarn flattening and achieves yarn turning round wires.

13- STANDARDISATION OF RESULTS:

To standardize the results of the test method, atmospheric conditions (temperature and relative humidity) must be either standard or registered. Sources of error must be eliminated by increasing accuracy in interlacing, cutting, and weighing. Interlacing must achieve maximum density of wires. Cutting must achieve complete interlacing repeats. Weighing must be as accurate as possible by using a balance of high sensitivity.

14- VERIFICATION:

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:

Wire diameter =4 mm Number of wires =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)	Calculated Yarn Density (mg/mm ³)
110.8	0.11063	1.2311
111.7	0.14402	0.7265
111.3	0.12918	0.9029
109.9	0.07724	2.5255
110.7	0.10692	1.3180
110.2	0.08837	1.9294
111.4	0.13289	0.8532
110.5	0.09950	1.5219
109.8	0.07353	2.7867
111.8	0.14773	0.6904
110.1	0.08466	2.1022
111.0	0.11805	1.0812
110.3	0.09208	1.7771
110.0	0.08095	2.2992
110.7	0.10692	1.3180
110.1	0.08466	2.1022
110.9	0.11434	1.1525
110.1	0.08466	2.1022
110.8	0.11063	1.2311
111.1	0.12176	1.0163

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

Table (2): Statistical Measures of Test Results:

Measure	Weight (mg)	Diameter (mm)	Density (mg/mm ³)
Mean	110.661	0.10544	1.5334
Standard Dev.	0.42757	0.02221	0.62589
Coeff. of Var. %	0.38638	21.06214	40.8176

If mean weight is used in calculations, yarn diameter will be 0.105465 mm and density will be 1.3547 mg/mm³.

Other known method [2] gave the value of diameter as 0.128 mm assuming yarn density to be 0.916 mg/mm³.

15- COMMENT:

It is clear from Table (1) that the range of weight values expressed as a percentage of the mean weight is 1.8. It is also clear that any small difference in measured weight results in a big difference in estimated value of both yarn diameter and yarn volumetric density. This can be observed regarding values of coefficient of variation shown in Table (2).

To overcome the problem of poor repeatability of results, number of tests is increased and yarn diameter is calculated from the mean value of weight. Yarn volumetric density is also calculated from the mean value of weight.

15- CONCLUSION:

By this research work two big and main problems could be solved: the first is measuring yarn diameter irrespective of type of its material, and its way of production i.e. irrespective of its structural details, and the second is measuring yarn volumetric density depending only on yarn count and the data obtained from the same test. The solution of these two problems will open the way towards assessing many depending properties and structural details of yarns and fabrics. It is hoped that all yarns will be specified by diameter and volumetric density like any other engineering material.

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