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A NEW METHOD FOR MEASURING FABRIC THICKNESS
&
DETERMINING FABRIC VOLUMETRIC DENSITY

طريقة جديدة لقياس سمك القماش وتحديد كثافته الحجمية

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خلاصة :

يقدم البحث طريقة جديدة لقياس سمك القماش ايا كان نوعه سواء كان منسوجا أم غير منسوج أم قماش تريكو، وكذلك أى منشأ مستو سهل الانثناء بغض النظر عن قابليته للإنضغاط . وتعتمد فكرة البحث على الاستفادة من العلاقات الرياضية والتفسيرات الفيزيائية فى ايجاد طريقة دقيقة لقياس مسافة دقيقة مثل السمك مع الأخذ فى الاعتبار صعوبة قياس السمك بشكل مباشر نظرا لعدم إمكانية تحديد حدود سمك القماش. وقد نتج عن هذا البحث تطوير طريقة قياس الوزن بدلا من قياس السمك ثم التعويض فى علاقة رياضية بسيطة رغم دقتها لحساب سمك القماش وتعبر النتيجة الأخيرة عن سمك القماش ليس فى موضع قياس واحد فى القماش ولكن فى عدد من الأماكن وذلك فى التجربة الواحدة، اى أن القيمة المحسوبة تعتبر متوسطا حسابيا لعدد من القراءات يتم التوصل اليها دون ايجاد هذه القراءات. وتتلخص الطريقة فى تعريج شريحة من القماش ذات طول وعرض مناسبين وذلك بدورانها حول أسلاك دائرية مستقيمة او اسطوانات متماثلة معروفة التطر بشكل تبادلى بحيث تكون امام سلك وخلف السلك التالى وهكذا وبحيث تكون الأسلاك فى مستو واحد. يتم بعد ذلك فصل جزء القماش المتعرج ووزنه وعد الأسلاك ثم يتم التعويض فى معادلة بسيطة لإيجاد سمك القماش وبمعلومية وزن قطعة القماش التى تم تعريجها وبمعلومية طولها وعرضها وسمكها أمكن التعبير عن الكثافة الحجمية للقماش.

1-Abstract:

In this paper a new scientific method is developed to measure the thickness of any three-dimensional limp structure such as fabrics whatever their type (woven, non-woven, knitted, etc), paper, and so on. The necessary condition is that these structures are very easy to bend. This method depends on mathematical relations and physical interpretations which are used to replace *direct thickness measuring* by *fabric weight measuring* after shaping (*corrugating*) it round light circular straight identical *wires* placed in one plane in a jamming situation. A formula is derived to obtain fabric thickness as a function of weight of corrugated fabric, wire diameter, and number of wires used. The result obtained for fabric thickness may be considered as an average value of a number of readings equal to the number of wires. Corrugating plane is preferred to be inclined to the vertical direction to avoid fabric compression Wire diameter must be proportional to both fabric thickness and fabric flexural rigidity. This means that, to make bending and therefore corrugating easier, wire diameter and angle of inclination, must be properly chosen. The idea of a new fabric thickness meter called *HFTM* is explained.

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2- Introduction:

Fabric thickness measurements are involved directly in a wide range of technological investigations related to milling or raising, heat transmission and insulation, tactile judgment, design of specific fabric, or studying fabric geometry. Thickness at low pressure is useful in applications for bulk and heat insulation whereas thickness at considerable pressures is useful in applications such as armature winding. The relation between pressure and thickness is useful in studying softness of handle and fabric compressibility. Fabric thickness measurement needs suitable pressing feet, dial gauges, and pressures [1]. Macdonald [2] designed an instrument that could apply pressures as low as 0.001 $lb/in.^2$. Kawabata [3], and Shirley [4] used different fabric thickness meters but their results are highly correlated [5]. CSIRO [5] developed a series of instruments that are inexpensive, robust, and simple to use and their related test methods. This series is called FAST (Fabric Assurance by Simple Testing). FAST-1 gives a direct reading of fabric thickness over a range of loads with micrometer resolution. The FAST-1 compression meter measures fabric thickness over a circular area of 10 cm^2 at 2 g/cm^2 and 100 g/cm^2. Surface thickness is defined as the difference between the two measured thicknesses. De Jong, S., and Tester, D. H. [6] regard a fabric as consisting of an incompressible core and a compressible surface layer They state that the degree of fabric compression affects the thickness of the fabric surface layer and consequently the appearance and handle

CSIRO [5] defines very flexible fabrics as those having a weight less than 200 g/m^2 and having therefore low bending rigidity. NING PAN et al. [7] used data on selected fabrics of different fibre types, weave constructions, and fabric thickness to "fingerprint" or characterize fabrics. They state that fullness and softness as well as finish stability are all related to fabric compressional properties They used the Instron to measure compression and fabric thickness by providing a suitable compression cell and maintaining optimum compression load. Kawabata [8] measured fabric thickness at 0.5 g/cm^2 and defined fullness and softness as a feeling which comes from bulky, rich and well formed feeling. He stated that springy property in compression and thickness accompanied with warm feeling are closely related with this feeling.

Yarn diameter shares the weave structure in determining thickness of woven fabric. Fabric thickness could be determined under different pressures. Vitro, L. and Naik, A. [9] found that fabric thickness t is related to normal pressure P according to the relation $P^b t = a$, where a and b are constants depending on fabric details Ebraheem [10] assumed that thickness of a fabric woven from a warp and a weft at right angle is simply equal to the sum of warp yarn diameter and weft yarn diameter

The same problem as in measuring yarn diameter arised during measuring fabric thickness But the problem was more difficult and complicated as we have not only one yarn but two different yarns i.e. warp and weft, and we have a new structure i.e. fabric. It is not easy to measure fabric thickness as it is neither visually determined nor dimensionally stable. It is also difficult to be calculated because the calculation of fabric thickness depends on fabric volumetric density which depends on fabric structure, and yarn volumetric density. Ebraheem [11] expressed volumetric density of plain square woven fabric as a function of yarn cover ratio and yarn volumetric density. Trials have been made to develop instruments that measure fabric thickness under specific pressures [9]. These pressure values don't distinguish the differences between different fabrics as the same pressure is used for a variety of fabrics.

Yigit [12] developed a computer model to estimate fabric resistance to heat transfer depending on fabric resistance data and fabric thickness data for clothes.

McCullough [13] discussed factors affecting insulation and evaporative resistance of cloth. These factors included fabric thickness, fabric density, body surface area covered by garment, evenness of fabric distribution on body, the increase in surface area for heat loss due to clothing, the looseness of tightness of fit, person's body position (sitting or standing), body motion, and wind. McBride [14] studied the microstructure in dry plain weave fabric during large shear deformation in terms of yarn width, yarn spacing and fabric thickness. Klein [15] described analysis and characteristics of fabric used as an electrode separator. Effects upon cell performance resulting from changes in separator fabric thickness were analysed. Stylios [16] prognosed seam pucker based on a mathematical model developed from extensive sewing experiments and on the measurement of fabric thickness and flexural rigidity. Take-uchi-M et al [17] described the heat transfer experiments and theoretical predictions of cylinders covered with `knicker hose`, `camel underwear`,`body lights` and `nylon stocking` respectively. They stated that heat transfer behaviour depends primarily on the fabric thickness and the state of contact with the cylinder

From previous introduction it is clear how fabric thickness is important and how its measuring is difficult. Fabric thickness at low pressure is difficult to be measured but it has many applications. In this paper a new strategy is planned. This strategy fulfils achieving three decisions. The first decision is avoiding the problems of minimum pressure. The second is avoiding the problem of presser foot dimensions. The third is avoiding the problem of dial gauges compatibility This strategy depends on weight measurement, counting and calculating to measure fabric thickness and determine fabric volumetric density.

3- Deriving Mathematical Relations:

If a strip of fabric interlaces with straight circular wires according to the rule of plain weave in such a manner that wires reach the jamming state without compression and occupy one plane, then the fabric-wires assembly will produce a geometrical model. This model can be analytically defined in terms of fabric thickness, wire diameter, and number of wires. If

D : wire diameter (mm)

N :number of wires

t : fabric thickness (mm)

then the length of fabric strip which makes complete interlacing repeats with wires can be determined from the following relation:

$$l_t = \frac{\pi N(D+t)}{2} \tag{1}$$

l_t . length of fabric strip lapping around wires (mm)

To express weight of fabric strip lapping around wires, two other informations must be given: strip width and fabric weight per unit area. If

b ·width of fabric strip (mm)

ω : fabric weight per unit area (g/m^2)

then

$$W = l_t b\omega \tag{2}$$

W :weight of fabric strip lapping around wires (g)

From (1) and (2)

$$\therefore W = \frac{\pi N b\omega(D+t)}{2*10^6} \tag{3}$$

From (3)

$$\therefore t = \frac{2*10^6 W}{\pi N b \omega} - D \qquad (4)$$

Equation (4) shows that fabric thickness can be expressed in terms of parameters of the foregoing geometrical model besides an intrinsic property of the fabric (fabric weight per unit area). These parameters are wire diameter, number of wires, strip width, and weight of fabric strip lapping around wires.

Fabric volumetric density can be expressed in terms of fabric weight per unit area and fabric thickness as follows:

$$\rho_f = \frac{\omega}{1000t} \qquad (5)$$

ρ_f . fabric volumetric density (g/cm^3)

From (4) and (5)

$$\therefore \rho_f = \frac{\omega}{\left[\dfrac{2*10^9 W}{\pi N b \omega} - 1000D\right]} \qquad (6)$$

From (6) fabric specific volume υ (cm^3/g) can be expressed as follows:

$$\upsilon = \frac{\left[\dfrac{2*10^9 W}{\pi N b \omega} - 1000D\right]}{\omega} \qquad (7)$$

4- Building on Scientific Basis:

Simply, we can say if you want to determine the thickness of a fabric without going into problems of suitable pressure, suitable presser foot diameter, or dial gauge accuracy, please corrugate a rectangular strip of this fabric by lapping it around identical cylinders of suitable diameter according to the rule of plain weave This means that lapping must be in an alternative manner It is also required that cylinders lie in one plane and reach the jamming state This makes lap angle around each cylinder equal to 180°. It is then required to remove fabric outside the lapping zone This needs cutting the fabric protruding outside this zone.

5- Developing a New Fabric Thickness Meter:

The idea of this new fabric thickness meter which is called HFTM is based on the previous mathematical analysis. The device consists of :

- a base plate with two fulcrums 30 cm in between,
- two slotted straight bars each with a possibility to be fulcrumed with base plate,
- a rectangular straight bar to connect slotted bars is needed to be mounted between them at a suitable distance from fulcrum,
- 2 pairs of clamps with a possibility to be mounted on the crosswise bar,
- a number of cylinders of a diameter proportional to fabric thickness and fabric bending stiffness, and of ends suitable to pass through slots,
- a sharp cutter.

The height of the device depends on the class of fabrics tested (thin, medium, or thick). The bar frame can be tilted and fixed at a suitable angle with vertical to facilitate the corrugating process. A digital electronic balance which measures to the nearest milligram is suitable for weighing corrugated fabric sample.

6- Test Procedure:

6-1- Preparing Fabric Specimen:

A strip of fabric is cut in a rectangular form with a sufficient length and a suitable width for corrugating (lapping process).

6-2- Lapping:

Fabric strip is clamped by two pairs of clamps in its two extremities. One pair of clamps is fixed to the crosswise bar on the bar frame. The other clamp is gripped by a hand and a cylinder is inserted gently by the other hand through the two slots till it reaches the fixed clamp as shown in Fig. (1). The first hand is moved (with clamp) to the other side of the bar frame to cover the previous cylinder and another cylinder is inserted by the other hand as shown in Fig. (2). This procedure is repeated till a considerable length of fabric is lapped around a suitable number of cylinders.

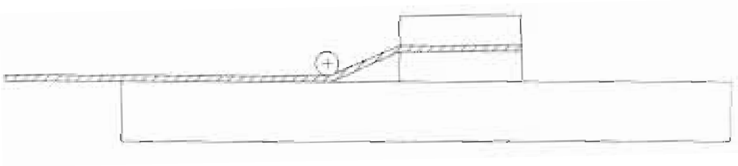

Fig. (1): One pair of clamps on base plate and first cylinder is inserted on fabric strip after passing through the two slots (not shown)

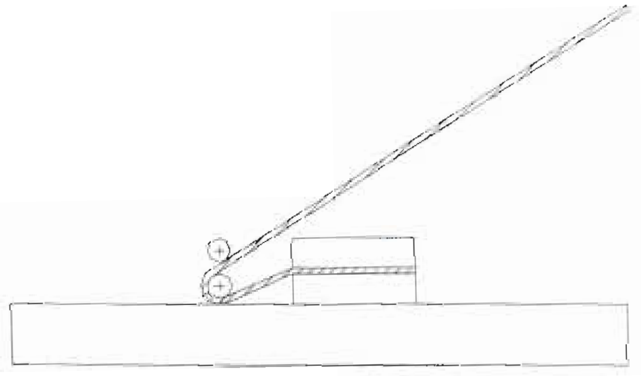

Fig. (2): The second pair of clamps is moved to the other side and another cylinder is inserted on fabric strip after passing through the two slots

6-3- Cutting:

Strip parts outside lapping zone are removed by cutting it at a two corresponding points: one just before the first cylinder, and one just after the last cylinder in such a manner that complete lapping repeats are obtained

6-4- Weighing:

Corrugated fabric strip is accurately weighed.

7- Data Obtained From The Test:

Data obtained from this test are strip width b, weight of corrugated fabric strip W, cylinder diameter D, and number of cylinders N.

8- Determining Fabric Thickness:

Substituting for fabric weight per unit area and data obtained from the test in equation (4) fabric thickness is determined.

9- Determining Fabric Volumetric Density:

Substituting for the same previous data in equation (6) fabric volumetric density is determined

10- Conclusion:

By this test method real fabric thickness and fabric volumetric density can be determined This method can be used to test any flexible 3-dimensional structure irrespective of whether it is a fabric (woven, non-woven, knitted, etc.) or another material like paper etc The philosophy behind this new method for fabric thickness measurement is that we do not deal mathematically with fabric thickness in a direct way We deal mathematically with neutral plane of the fabric Length of fabric neutral plane is the actually measured value or property. This length is not affected by fabric flattening if it occurred Fabric flattening occurs in a neighbourhood of fabric napping point between cylinders. We don't measure this length directly but we weigh the fabric strip corresponding to it (length of test specimen which makes complete lapping repeats with cylinders). This weight is divided by fabric weight per unit area to give the area of the weighed fabric strip This area is not affected by flattening Dividing this area by strip width gives straight length of weighed fabric strip This length is a pure function of cylinder diameter, number of cylinders used, and fabric thickness without flattening i.e. real fabric thickness. This is the value of fabric thickness under zero pressure. Thus the *HFTM* can solve the problem of measuring fabric thickness and can besides measure fabric volumetric density.

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