DETERMINING FABRIC THICKNESS UNDER ZERO PRESSURE WITHOUT MEASURING ANY DIMENSIONS

تحديد سمك القماش تحت ضغط صفر دون قياس أي أبعاد

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خلاصة :

يقدم البحث طريقة علمية جديدة لقياس سمك أي منشأ مستوي ثلاثي الأبعاد سهل الانثناء كالأقمشة بأنواعها (المنسوجة - غير المنسوجة - التريكو - ..الخ) ، والورق ، وهكذا. ويتطلب الاختبار إعداد شريحة مستطيلة الشكل دون الحاجة إلي قياس طولها أو عرضها. وتعتمد طريقة القياس علي العلاقات الرياضية والتفسيرات الفيزيائية التي تستبدل القياس المباشر للسمك بقياس وزن شريحة القماش بعد تشكيلها (تعريجها) حول أسطوانات دائرية خفيفة متماثلة القطر موضوعة في مستوي واحد وفي حالة ازدحام نهائي. وتكرر عملية التشكيل مع شريحة أخري من القماش باستخدام نفس العدد من الأسطوانات ولكن بقطر أخر. وفي كل حالة يتم وزن جزء الشريحة الذي يكون تكرارات صحيحة حول الأسطوانات ، فنحصل علي وزنين مقابل القطرين المستخدمين. وتستخدم الأقطار المناسبة لسمك وصلابة ثني القماش بحيث تسهل عملية التشكيل . ويقدم البحث صيغة لحساب سمك القماش بمعلومية القطرين والوزنين. كما يقدم البحث فكرة الجهاز المستخدم في التشكيل.

ABSTRACT

In this paper a new scientific method is developed to measure thickness of any three-dimensional limp structure such as fabrics whatever their type (woven, non-woven, knitted, etc.), paper, and so on. Material needed for testing must have a perfect rectangular strip shape. There is no need to know how long or how wide the tested sample is. The necessary eondition 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 *cylinders* placed in one plane in a jamming situation. Fabric shaping is repeated on another part of fabric strip but with another cylinder diameter. This results in a new eorrugated fabric weight. A formula is derived to obtain fabric thickness as a funetion of two weights of corrugated fabric and two cylinder diameters. Cylinder diameter must be proportional to both fabric thickness and fabric flexural rigidity. This means that, to make bending and therefore corrugating easier, cylinder diameter must be properly chosen. The idea of a new fabric thickness meter ealled *HFTM* (Hamdy Fabrie Thiekness Meter) is explained.

1- INTRODUCTION

Measuring dimensions of a solid body could be achieved by using a ruler, a gauge, a planimeter, or by getting use of its physical and ehemical properties. The problem in textiles is that boundaries of structure are difficult to be located.

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 fabrie compressibility. Devices based on compression are of doubtful use

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in measuring thickness because of the interaction of count and twist in determining compressibility. Fabric thickness measurement needs suitable pressing feet, dial gauges, and pressures [1] Mcdonald [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

$$P^b t = a \qquad \text{(i)}$$

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 he 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 diameter, 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. Fabric thickness is important in fabric pleating process. For successful pleating, firm, stiff fabrics are required. With thick fabrics it is not possible to obtain a sharp pleating angle and fabrics which pleat well usually have a high bending length and low thickness, i.e. high bending modulus. Important properties to investigate fabric handle are stiffness, smoothness, cloth weight, cloth thickness, hardness, and cover factor. It was concluded that it is possible to give a fairly complete description of handling properties in terms of fabric stiffness, smoothness, and thickness . It has been suggested that thickness measurements on the specimens under abrasion resistance test give the rate of wear [18].

Fabric thickness may change after use due to yarn or fibre migration. Repeating bending of webbings used as seat belts in cars caused a drop of about 8 % in strength and an increase in webbing thickness of about 3.2 % after 500,000 fatigue cycles, indicating relative movement of fibres and yarns in the fabric. Outside the bending region there was a decrease in thickness of about 2 % [19]. Texture modification of carpets was assessed by computer generated carpet-like textures and covariance data. Covariance data allowed measuring period frequency, amplitude, and overall mean. Some thoughts on modelling carpet texture appearance loss with the aid of simulated texture images was also offered [20]. After use, fabric thickness decreases due to yarn flattening. Yarn flattening and fabric extension cause reduction in yarn crimp ratio Fabric weight per unit area will be decreased [21].

2- THEORY OF TEST METHOD

If a strip of fabric interlaces with straight circular cylinders according to the rule of plain weave in such a manner that cylinders reach the jamming state and occupy one plane, then the fabric-cylinders assembly will produce a geometrical model. This model can be analytically defined in terms of fabric thickness, cylinder diameter, and number of cylinders. If

D : cylinder diameter (mm)

N : number of cylinders

t : fabric thickness (mm)

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

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

l_t : length of fabric strip lapping around cylinders (mm)

To express weight of fabric strip lapping around cylinders, two other informations must be used: 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 cylinders (g)

From (1) and (2)

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

From (3)

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

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 cylinder diameter, number of cylinders, strip width, and weight of fabric strip lapping around cylinders. If fabric weight per unit area is not known or if it can not be obtained as accurately as required, another sample of the same fabric with the same width is corrugated with the same number of cylinders but of a different diameter. If new diameter is D', and the weight of the corresponding corrugated fabric is W', the last relation will be

$$t = \frac{2 * 10^6 W'}{\pi N b \omega} - D' \tag{5}$$

From (4) and (5)

$$t = \frac{W' D - W D'}{W - W'} \tag{6}$$

The last equation expresses fabric thickness as a function of two weights and two diameters Increasing strip width and number of cylinders affect reducing the influence of eutting accuracy.

3- 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 and without needing to know fabric weight per unit area, 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. The last procedure is repeated with another sample of the same fabric with changing only cylinder diameter. With these data it is possible to calculate fabric thickness.

4- DEVELOPING A NEW FABRIC THICKNESS METER

A small device equipped with groups of circular light rigid straight cylinders of different diameters is built. Cylinders may be made hollow if possible. Cylinder diameters are 4, 5, 6, 8, 10, and 12 mm to be suitable for fine and coarse fabrics. The device consists of two slotted straight bars connected by a back plate to give a working distance of 63 mm betwcen the two slots which are facing each other. The two ends of each cylinder are made cylindrical with a radius of clearance with the slot width (4 mm) and a length equal to the slot depth This clearance facilitates inserting cylinders one after the other during fabric strip corrugating. A base plate 61 mm wide is mounted to the back plate. Two fabric strip clamps of length 80 mm are also used. The instrument is equipped with more similar clamps to facilitate preparing more than one fabric strip from the same fabric. The bar frame occupies a space of 500 mm * 100 mm * 52 mm. 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 0 1 milligram is suitable for weighing corrugated fabric sample. A sketch of the device is shown below.

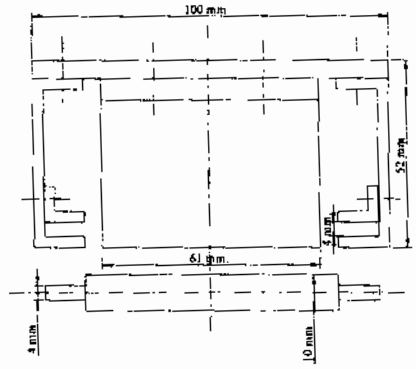

Fig. (1): A sketch of the device (a plan view) indicating the two vertical 4-mm slots, the 61-mm wide base plate, and one 10-mm diameter cylinder drawn separately

Figure (2) shows an isometric of the device.

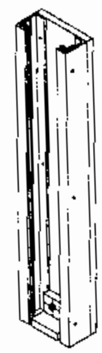

Fig. (2): An Isometric of Interlacing Device

5-TEST PROCEDURE

5-1- Preparing Fabric Specimen:

A strip of fabric is cut in a rectangular form with a sufficient length and a suitable width for corrugating (lapping proeess). A sharp cutter and a template (60 mm wide) are used for this purpose.

5-2- 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. The first hand is moved (with clamp) to the otber side of the bar frame to cover the previous cylinder and another cylinder is inserted by the other hand This procedure is repeated till a considerable length of fabric is lapped around a suitable number of cylinders.

5-3- Cutting

Strip parts outside lapping zone are removed by cutting it at 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. The sharp cutter is used for this purpose.

5-4- Weighing:

Corrugated fabric strip is accurately weighed to the nearest 0.1 mg.

5-5- Repeating the Test:

The previous steps are repeated with another part of the fabric changing only cylinder diameter

5-6- Tabulating Data:

Data obtained from repeated lapping and weighing are put in a table to be used in calculations. In the title of the table, atmospheric conditions with respect to temperature and relative humidity are mentioned.

5-7- Calculating:

Fabric Thickness is determined by substituting for the test data in equation (6). With every pair of measurements, a value of fabric thickness is calculated.

6- DATA OBTAINED FROM THE TEST

Data obtained from this test are first weight of corrugated fabric strip W, first cylinder diameter D, second weight of corrugated fabric strip W', and second cylinder diameter D .

7- DETERMINING FABRIC THICKNESS

Substituting for data obtained from the test in equation (6) fabric thickness is determined.

8- NUMBER OF FABRIC THICKNESS READINGS

If test procedure is carried out m times with m different cylinder diameters, then m different weight values of corrugated fabric are obtained. Making computations of 2 between these m results, a number of fabric thickness readings n is obtained. The relation between number of fabric thickness readings and number of samples is as follows:

$$n={}^{m}C_{2}=\frac{m(m-1)}{2} \qquad (7)$$

m : number of fabric samples lapped or number of cylinder sets used.

n number of fabric thickness readings.

It is clear from equation (7) that beginning from 4 cylinder sets, number of thickness readings will be more than number of test specimens. This is indicated in Table (1).

Table (1): Number of Fabric Thickness Readings (n) Obtained from Lapping and Weighing Procedures (m)

m	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
n	0	1	3	6	10	15	21	28	36	45	55	66	78	91	105
m	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
n	120	136	153	171	190	210	231	253	276	300	325	351	378	406	435

9- PHILOSOPHY BEHIND TEST METHOD

The philosophy behind this new method for fabric thickness measurement is that it is not dealt mathematically with fabric thickness in a direct way. It is dealt 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. This results in a slight local change in fabric configuration around every cylinder but there will be no fabric migration from one cylinder to the next depending on fabric flexibility. Therefore, the effect of flattening or compressibility will not be translated to corrugated fabric length. Measuring fabric strip weight to the nearest 0.1 mg is a simple task. There is no need to measure any dimensions such as length or width. There is also no need to know or measure fabric weight per unit area Calculating fabric thickness from accurate weights and cylinder diameters results in obtaining fabric thickness not only to the nearest 0.05 mm but to the nearest 0.1 micron or more accurately.

10- VERIFICATION

To verify the applicability of this test method, two fabrics which are very poor in regularity were tested.

10.1. FIRST FABRIC:

10.1.1. At a temperature of 24 °C and a relative humidity of 68 %, eight samples were tested. Number of cylinders used for lapping were 34. Two cylinder diameters were chosen: 4 mm and 10 mm.

At 4-mm diameter weights of corrugated samples in mg were:

2744.8 2756.6 2836.5 2799.6 2961.2 2828.1 2684.9 2732.3

Average weight = 2793 mg Coefficient of variation = 3.04 %

At 10-mm diameter weights of corrugated samples in mg were:

6383.5 6700.9 6546.8 6414.8 6857.5 6813.6 6501.6 6449.9

Average weight = 6583.5 mg Coefficient of variation = 2.7899 %

Fabric Thickness obtained from Equation (6) =0.4210526311 mm.

10.1.2. At a temperature of 22 °C and a relative humidity of 62 %, eight samples were tested. Number of cylinders used for lapping were 34. Two cylinder diameters were chosen: 4 mm and 10 mm.

At 4-mm diameter weights of corrugated samples in mg were:

2747.8 2752.5 2796.9 2761.6 2957.0 2721.9 2806.4 2683.1

Average weight = 2778.4 mg Coefficient of variation = 2.9551 %

At 10-mm diameter weights of corrugated samples in mg were:

6421.5 6687.3 6556.7 6436.2 6812.8 6800.0 6490.0 6333.3

Average weight = 6567.2 mg Coefficient of variation = 2 7788 %
Fabric Thickness obtained from Equation (6) =0.39991554 mm

10.2. SECOND FABRIC:

10.2 1. At a temperature of 22 °C and a relative humidity of 62 %, ten samples were tested. Number of cylinders used for lapping were 30. Two cylinder diameters were chosen. 5 mm and 10 mm.

At 5-mm diameter weights of corrugated samples in mg were:

1471 5 1411.1 1444.3 1366.3 1458.5 1438.8 1321.3 1480.4
1432.7 1436.8

Average weight = 1426.2 mg Coefficient of variation = 3.4266 %

At 10-mm diameter weights of corrugated samples in mg were:

2666.2 2928 6 2996.4 2969.0 3038 1 3006.0 2974.7 2906.0
2732.1 2867.1

Average weight = 2908.5 mg Coefficient of variation = 4.1981 %
Fabric Thickness obtained from Equation (6) = 0.1892 mm

11.2.2. At a temperature of 22 °C and a relative humidity of 62 %, twenty samples were tested. Nnmber of cylinders used for lapping were 30. Two cylinder diameters were chosen: 5 mm and 10 mm.

At 5-mm diameter weights of corrugated samples in mg were:

1471.5 1411.1 1444.3 1366 3 1458 5 1438 8 1321.3 1480.4
1432 7 1436 8 1467.6 1407.0 1440 3 1361.6 1455.0 1434.8
1323.8 1470.8 1428.7 1435.6

Average weight = 1425.6 mg Coefficient of variation = 3.3711 %

At 10-mm diameter weights of corrugated samples in mg were:

2666 2 2928.6 2996.4 2969.0 3038.1 3006.0 2974.7 2906.0
2732.1 2867.1 2921.0 2986.3 2960.4 3031 7 2996.6 2964.4
2899.0 2724.4 2856.5 2664.1

Average weight = 2904.4 mg Coefficient of variation = 4 0668 %
Fabric Thickness obtained from Equation (6) = 0.1799 mm

11- CONCLUSION

By this test method real fabric thickness can be determined. This method can be used to test any flexible 3-dimensional structure irrespective of whether it is a fabric (woven, nonwoven, knitted, etc.) or another material like paper etc. It is not needed to measure any longitudinal dimensions like length and width of fabric There is also no need to know or measure fabric weight per unit area. The influence of fabric softness on thickness measurement could be avoided by the developed test method. Thus the *HFTM* (Hamdy Fabric Thickness Meter) can solve the problem of measuring fabric thickness.

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