POROSITY DETERMINATION OF JERSEY STRUCTURE

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Abstract:

In our paper, we attempt to investigate methods of determining jersey porosity which is this fabric's principal physical characteristic. In fact, end use, liquid absorbency, thermal comfort and resistance are closely related to pore size and distribution. So it is important to study porosity, in order to classify and determine the right use of jersey knitted structure. Many methods are used to estimate porosity, but most concern air permeability, image processing and geometry modelling. The first mentioned is used for the stretched structure, the second is valid for fabrics with high porosity levels, and the last mentioned is used to confirm any structure's conformation.

The aims of this study are twofold; firstly, to recognise the most suitable and easiest method of estimating the fabric's porosity, and secondly to study the influence on porosity of various knitting parameters of jersey structure such as yarn number and count, fabric thickness, loop length, and stitch density.

Key words:

jersey, porosity, knitted structure geometry, image processing, air permeability, geometrical modelling

1. Introduction

Knitting structures are important because they offer several advantages. Physically, they present properties of comfort such as high elasticity, conformity with the shape of the body, softer and better touches feeling of freshness, and others. Porosity is one of the important physical propertieswhich has an influence on comfort and the aspect of use.

By 'porous media' we refer to a solid of an unspecified form delimiting and including vacuums called 'pores' filled with liquid and gas. These vacuums can communicate between each other to exchange matter and energy, as illustrated in Figure 1. The solid part, called the 'matrix', can be deformable, but it must have fundamental cohesion [9].

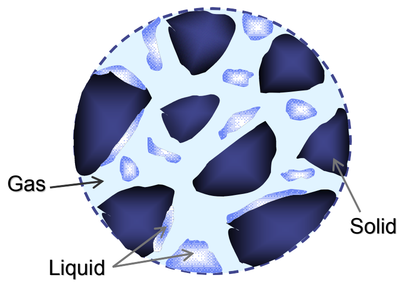


Figure 1. Geometry of a porous medium

Phenomena taking place in porous media depend on the geometry of the solid matrix, which can be:

- unconsolidated (grains or fibres are not welded between them), or
- consolidated (stamped solid compacts cannot be divided into grains).

Thus knitwork is a porous medium with a consolidated and deformable solid matrix.

Porosity (ε) is characterised by a certain number of average, geometrical or static sizes and is usually defined as being the volumetric ratio of the pores accessible by total volume [1]:

$$\varepsilon(\%) = \frac{V_a}{V_T} \tag{1}$$

where:

- V_a is the volume of the accessible pores through which the flow of the fluid masses is carried out, and
- V_T is the total volume of the sample.

The porosity of textile fabrics can be evaluated according to several methods. The most commonly used are classified according to three types [3]:

1. Air permeability
2. Image processing
3. Geometrical modelling

The first method is applicable for the tightened structures; the second, based on light transmission, is used for light structures; geometrical modelling can be generalised for any structure's conformation.

2. Determining porosity

2.1. Air permeability

According to standard NF G 07-111, porosity is expressed by the relationship between the air flow through a fabric (Q_{Ve}) and air flow to vacuum (Q_{V0}).

$$\varepsilon(\%) = 100\frac{Q_{Ve}}{Q_{V0}} \tag{2}$$

2.2. Image processing

This method is based on carrying out pictures using a camera CCD. Images are represented on the grey scale (Figure 6) and analysed using specific software to determine porosity.
The device of imagery is composed by:

- a microscope and a camera CCD;
- a device ensuring the fixing of knitting under microscope;
- a display screen and a computer to record and analyse images.

2.3. Geometrical modelling

Many models have been proposed to characterise the geometry of knitted structure, and can be classified as shown in Table 1:

Table 1. Knitting geometry modelling

Purely geometrical	Energy methods	Elasticity theory	Empirical
Chamberlain [15]	Postle & Munden [11]	Semnani et al. [12]	Tompkins [12]
Pierce [10]	Shanahan & Postle [13]		Dutton [12]
Dalidowitch [8]	Hepworth & Leaf [5]		Sokolnikoff [14]
Doyle [2]	Hepworth [4]		Munden [7,8]
Leaf & Glaskin [6]			
Suh [15]			

Previous theoretical studies of knitted fabric geometry focused on defining the shape of the loop. In the purely geometrical models [10, 6, 15], the loop shape was first assumed and then geometrical parameters were adjusted to fit the experimental data. Moreover, several studies investigated the mechanics of knitted fabrics' structures using force analysis [11, 13, 5, 4]. In these works, the action of forces and couples were localised at single points on the yarn. Using symmetry consideration and the condition of the relaxed fabric, some components of forces and couples could be eliminated. Other works used geometrical and physical principles to assume the loop shape function, which is improved by adopting a buckled elastic rod theory [12].
However, empirical methods [7, 8, 12 and 14] were still used to fit these models to experimental results.

3. Mathematical formulation using geometric modelling

In order to determine porosity, we base our results on the Suh model, which was applied in the study of the swelling and deswelling of yarn. However, the formulation deduced depends on several parameters which can be a source of error. Thus, we have introduced another model.

3.1. Geometric modelling using the Suh model

As has been pointed out by Norwick [15], there are a wide variety of yarn cross-sections in knitted structures. Therefore, some simplifications are required when attempting to develop a theoretical geometric model. For the purpose of geometrical modelling, Suh assumed the yarn to have a circular cross-section and uniform diameter. Also, the curved portions of the loop are assumed to be the arc of a circle.

The top and side view of jersey loops are shown in Figure 2.

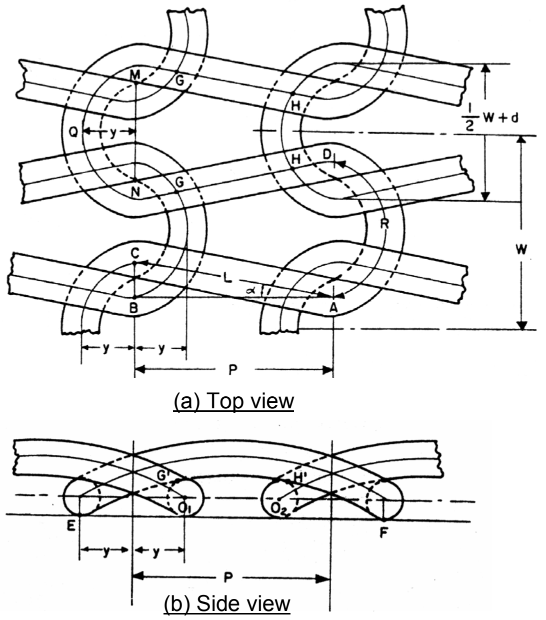


Figure 2. Top view and side view of jersey loops

where:

- d: the yarn diameter,
- P: the course spacing,
- y: the distance from the line MN to the loop tip Q,
- W: the loop width,
- L: the linear section length,
- α: the angle between lines AB and AC.

Figure 2 shows that:

$$V_T = t.w(p + 2y + d) \tag{3}$$

where V_T is the total volume of square containing the elementary stitch.

In order to determine the yarn volume, we have to know the volume of curvature (DA):

$$Volume\ de\ of\ Curvature\ \left(\overset{\frown}{DA}\right) = \pi \frac{d^2}{4} r\left(\pi - 2\alpha\right) \tag{4}$$

where α is determined as follow:

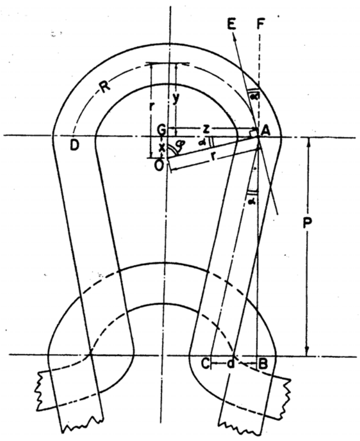


Figure 3. Curvature of the mesh in jersey

From Figure 3 we have:

$$Tan\alpha = \frac{d}{P} \ \Rightarrow\ \alpha = Tan^{-1}\left(\frac{d}{P}\right) \tag{5}$$

The radius of $\left(\overset{\frown}{DA}\right)$ is

$$r^2 = x^2 + Z^2 \tag{6}$$

where

$$x = ZTan\alpha \ = \left(\frac{1}{4}w + \frac{1}{2}d\right)\frac{d}{P} \tag{7}$$

So

$$r = \left(\frac{w}{4} + \frac{d}{2}\right)\sqrt{1 + \frac{d^2}{P^2}} \tag{8}$$

$$V_{Yarn} = V_{Straight\ Part\ [CA]} + V_{Curvature\ Part[DA]} = \pi \frac{d^2}{4}\left[2P + \left(\frac{w}{4} + \frac{d}{2}\right)\sqrt{1 + \frac{d^2}{P^2}}\left(\pi - Tan^{-1}\frac{d}{P}\right)\right] \tag{9}$$

Finally,

$$Total\ Porosity = \frac{V_{Vacuum}}{V_{Total}} = 1 - \frac{V_{Yarn}}{V_{Total}} \tag{10}$$

Substituting (4) and (9) in (10), we obtain

$$Total\ Porosity = 1 - \frac{\pi d^2 \left[8P + \sqrt{1 + \frac{d^2}{P^2}} \left(\pi - Tan^{-1} \frac{d}{P} \right) (2d + w) \right]}{16tw(d + P + 2y)} \quad (11)$$

This formulation, based on Suh's model, like other geometric models, is complex and requires many parameters to characterise the loop shape geometry. So we suggest a model requiring classical knitting parameters: course (*C*), wale (*W*), loop length (*l*), fabric thickness (*t*) and yarn diameter.

3.2. Proposed model

Our method consists in calculating porosity resulting from the geometrical representation of the elementary loop shape, with a circular section yarn as hypothesis. This is illustrated on Figure 4:

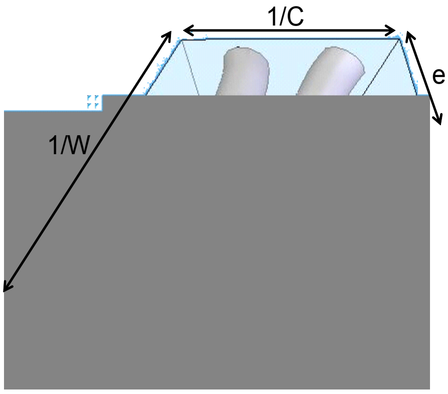


Figure 4. Three-dimensional elementary jersey loop shape

The yarn length of the elementary shape presented in Figure 4 is 2 × (loop length). By determining the course (C) per cm, wale (W) per cm, thickness (t), diameter (d) and loop length (l), we find that the porosity is as follows:

$$\varepsilon = 1 - \frac{\text{Yarn volume}}{\text{Total volume}} \quad (12)$$

However

$$\text{Yarn volume} = \frac{\pi \mathrm{d}^2.2.l}{4} = \frac{\pi \mathrm{d}^2 l}{2} \quad (13)$$

And

$$\text{Total volume} = \frac{1}{\mathrm{C}} \frac{1}{W} t = \frac{t}{WC} \quad (13')$$

Thus, the porosity becomes:

$$\varepsilon = 1 - \frac{\pi d^2 lCW}{2t} \quad (14)$$

where:

t: sample's thickness (cm);
l: elementary loop length (cm);
d: yarn diameter (cm);
C: number of courses per cm;
W: number of wales per cm.

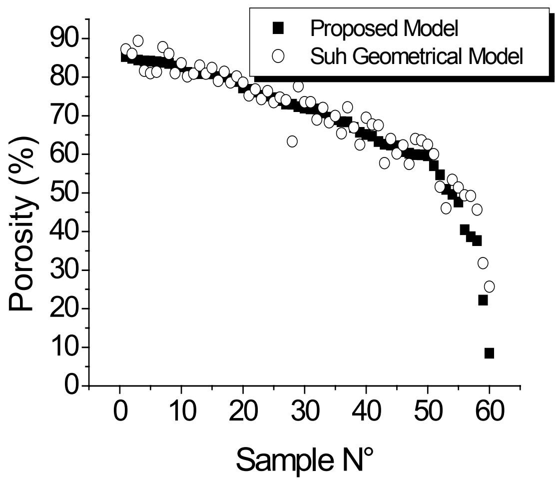


Figure 5. Porosity values using geometrical modelling

Experimental results and discussions

Geometrical modelling

In order to compare the values of porosity from geometrical modelling, we used 60 samples with various knitting parameters. From Figure 5, the porosity values derived from the two methods were correlated. However, Suh's geometrical model is complex and requires many parameters to characterise the loop shape geometry. For all subsequent values, the porosity values are given according to the proposed geometrical model.

Comparison of different methods

Comparing the methods of image processing, geometrical modelling (Equation 5) and that using air permeability, we obtain the result mentioned in Figure 6. Experiments were carried out on 60 samples divided according to various gauges (5, 7, 12, and 24) and different knitting parameters.

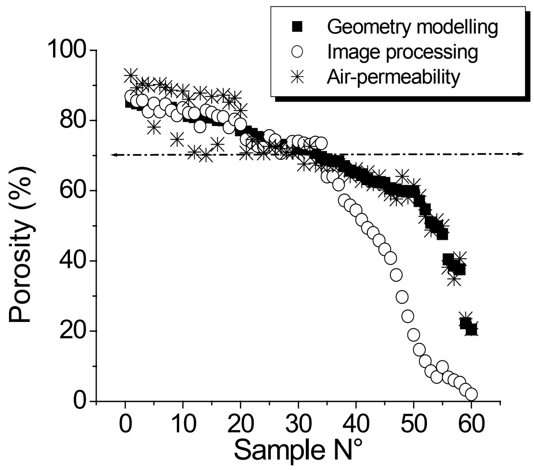


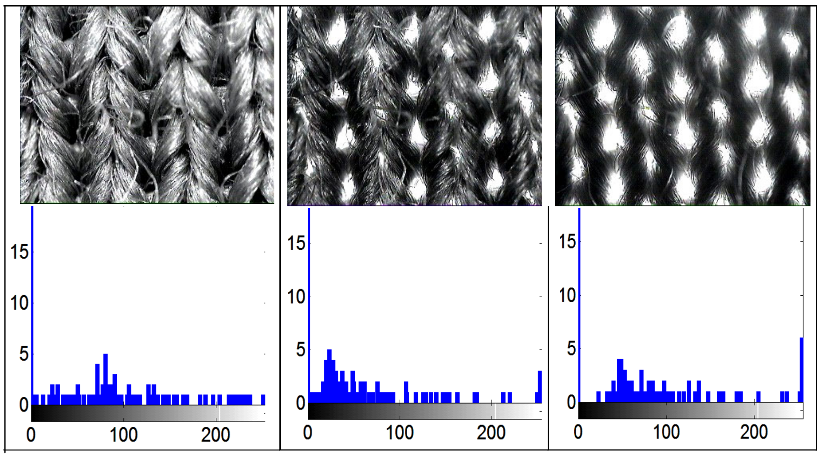
Figure 6. Porosity values according to various methods

From Figure 6, we can divide the porosity values into two intervals:

On the first scale range (up to 70%), the geometrical modelling and the image processing correlate. The air permeability values do not correspond because the structure is loose, and we note the supplementary flow loss caused by the vibrating fibres which are free to move. So the pore shape is not the same in the static and dynamic cases.

For tight structures, where porosity values are under 70%, the geometrical modelling and air permeability methods correlate. In fact, the loss of flow due to fibre vibration is reduced by the structure's conformation, which maintains the yarn and fibre assemblies. Image processing does not fit because the pore's shape shrinks and the light intensity is difficult to regulate.

Moreover, the choice of the light adjustment at the moment of the image capture can affect results. This is illustrated by Figure 7. For the same sample, we took three images with different light intensities. Image (a) is taken in a very low intensity, (b) with a medium intensity and (c) with a very high intensity. It is readily apparent that the pore's shape increases in the transition from (a) to (c). Moreover, even the shapes of pores change, and according to the histograms, we can notice a difference in the grey level distribution.



(a) : Low brightness (b) : Medium brightness (c) : High brightness

Figure 7. Light intensity's influence on pore shape

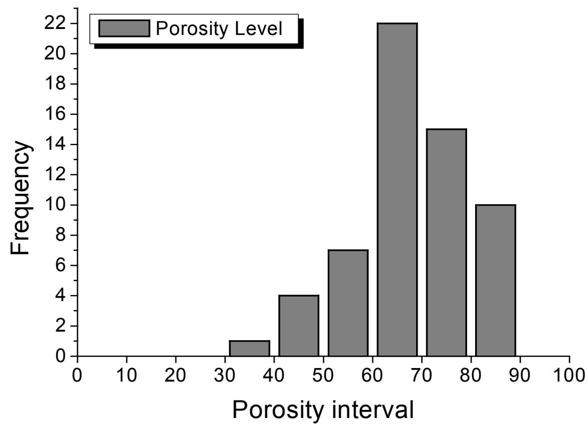


Figure 8. Porosity values of jersey

So, image processing and air permeability do not fit the whole interval of porosity values, and thus the geometrical modelling is the most suitable method. All the following porosity values are given using geometrical modelling.

Porosity interval

We carried out this study on 60 samples, with various parameters (gauge, yarn count number, matter, loop length, W, and C) and in conditioned atmosphere (20°C and 65% of moisture).

Figure 8 shows that the porosity of jersey is almost between 60 to 80%.

Influence of knitting parameters

For a constant yarn count number (2×35.71 tex), the same gauge (12) and using acrylic as yarn material, we varied the loop length (L), stitch density (N=W × C) and the thickness (t).

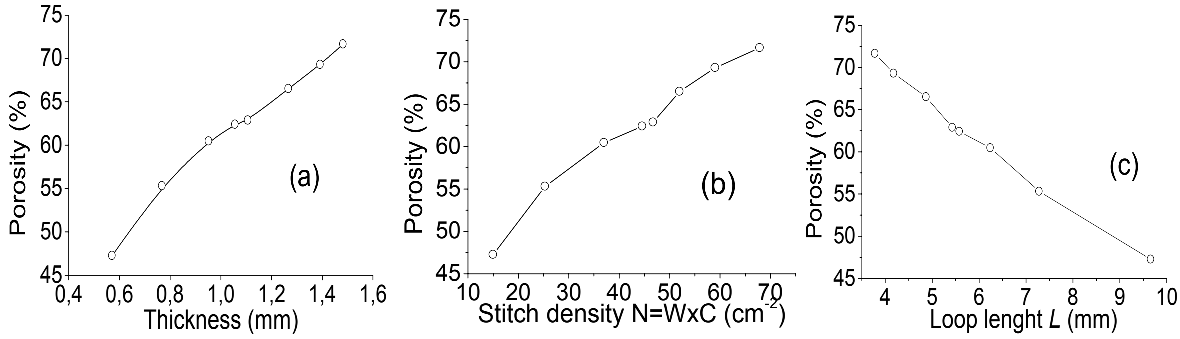


Figure 9. Knitting parameters' influence on porosity

The thickness is proportional to porosity, as seen in Figure 9a. This is because, when the thickness increases, the loop length decreases enormously (see Figure 10) and the pores' volume consequently increases.

Figure 9b shows that an increase in stitch density (N) (structures towards tight structures) increases the porosity. This is in contradiction with intuition. However we may note, according to Figure 10, that loop length variation is greater than stitch density variation. Indeed $\varepsilon = \frac{6.5793}{L^2}$ (Figure 10) has the same evolution as Munden's law.

Figure 9c shows that loop length is inversely proportional to porosity. In fact, an increase in the loop length implies a reduction in the volume of pores in knitting, and so a reduction in porosity.
We note that, according to Figure 9, the loop length's influence is more important than stitch density and thickness impact.

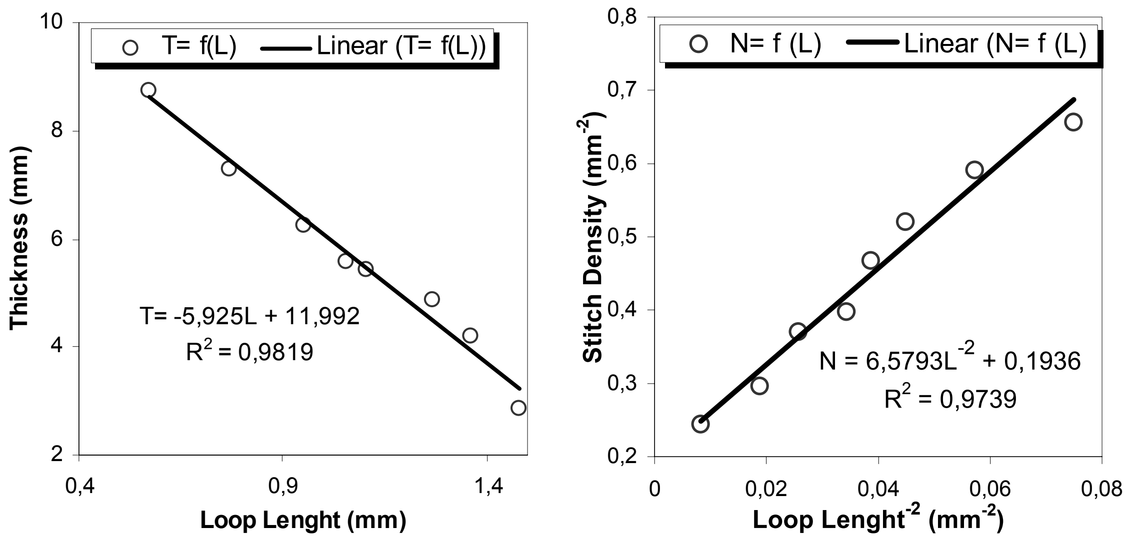


Figure 10. Variation of thickness (T) and stitch density (N) according to the loop length (L)

Yarn number influence

For the same yarn count number (41.67 tex) we varied the number of yarn under the same conditions (gauge = 12, loop length, W and C)

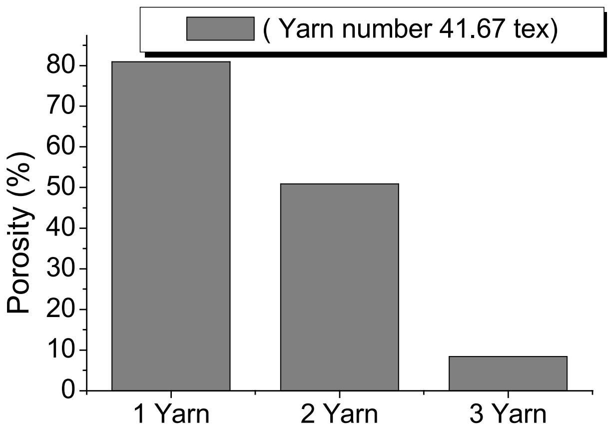


Figure 11. Yarn number effect on porosity

We note that the increase in yarn number influences porosity by decreasing the space of the pores, as seen in Figure 11. In fact, by increasing the yarn number, the volume of pores decrease and the yarns are flattened on the surface. This is the same phenomenon as seen from the yarn count number.

Conclusion

The main conclusion of this study is that geometry modelling is the most suitable and easiest method to determine porosity, and it can be generalised for any conformation. The porosity of knitted jersey structure is between 60 and 80%.

The effect of the loop length has more influence on porosity than the stitch density and the thickness. Porosity is affected by yarn number or yarn count number.

Porosity is one of the main physical parameters that have a great influence on comfort properties, but we suggest studying the permeability which is related to permeability and has an impact on wetting properties.

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