Assessment of the pore opening size of knitted geotextiles by image analysis

Eric Blond
Eric Blond Consultant Inc.
eric@ericblond.com
+1-514-621-9934
www.ericblond.com

Why another standard?
* ASTM D4751:
  * Method A: Dry sieving with glass beads (historical method)
  * Method B: Porometer (~ ASTM D6767)
* CGSB 148.1 n°10
  * Hydrodynamic sieving
* ISO 12956
  * Wet sieving

However - there are problems which are specific to circular-knit geotextiles
Properties of knitted geotextiles

* Structure is manufactured and extremely regular
* Very low coefficients of variation on all properties for well-conducted tests
* Manufacturing parameters can be adjusted to provide the product with a very precise opening size
* The opening size is measured when applied to a pipe having a nominal diameter for which the geotextile is specifically produced

Typical knitted geotextiles

Typical structures complying to ASTM D6707:
* 2D: typical knitted geotextile
* 3D: tighter knitted geotextiles, with smaller opening sizes
Recent Advances in Geotextile Filtration Design: Pore Opening Size Measurement using a Porometer or an Optical Tests

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Testing knitted geotextiles per D4751-A (dry sieving)

- Product is highly deformable; procedure includes a controlled elongation to reflect ‘as applied conditions’
- Specimen preparation is NOT reliable. Requires pulling of the geotextile on the tube. Elongation on the circumference of the tube is typically not constant.
- Transfer of the product from the pipe to the clamp is a problem, adds an important source of errors
- Faulty test results are frequent – i.e., there may be one or two outliers on a series of five specimens.
- The procedure is not applicable to pipes with a small diameters (e.g., 2’’)

Testing knitted geotextiles per ISO 12956 (wet sieving)

- ISO 12956: an attempt to improve the technique was made (insertion of a stiff ring)

Annex C (normative)

Preparation of knitted socks for testing

Apply the knitted sock test specimen over the outside of the corresponding diameter of a 100 mm length of vertical tubing or measure above having the same diameter as the pipe material to which the test is attached.

Fig. 14

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knitted geotextiles can exhibit opening sizes up to 600 µm (D6707)

- not in the ‘comfort zone’ for porometer tests: the larger the opening, the lower the pressure to measure a BBP, hence the lower the precision.
- The issue with clamping the specimen under controlled stress conditions remains
- Displacement of the specimen from a hanging pipe to the test equipment (while under stress)?

14. Calculation of the O95 Opening Size Value

The calculation of opening size is based on the following equation:

\[ O = C \times P \]  \hspace{1cm} (1)

where:
- \( O \) = opening size in microns, µm,
- \( C \) = correlation factor determined per Annex A1, and
- \( P \) = pressure in Pascals (N/m²) obtained during the wet test at the flow rate that is 1 %, 2 %, or 5 % of the dry flow rate at the same pressure.

Solution considered

- Improve the stretching technique
- Better handling
- Save time
- Improve repeatability?
- Prefer a non-destructive technique, where the measurement is made while the specimen is in a well-controlled stress conditions
  - Avoid transfer of specimens from a pipe to a clamp.
- Benefit from a unique feature of the knitted geotextile: it’s low thickness = it is possible to see-through the openings!
Solution developed

* Optical technique
  * Direct measurement of a dimension
  * No glass beads!

* Use a dedicated stretching rig
  * Better control of the stress
  * Easier installation avoiding pulling the fabric
  * Possibility to make an optical measurement without moving the specimen

Optical solutions

There are other experiences with optical methods:
* RTA T1524 – New South Wales (stretching to percent increase of initial length)

* MQC at Dupont Luxembourg since ~2001
  * For lightweight heat bonded geotextiles
    (See next presentation)
Key results or a R&D Collaborative project

Tested products: Carriff knitted geotextiles
Opening size tests: Performed by CTT Group
Optical tests: Developed by Western University (formerly UWO)
Repeated by CTT Group

Stretching of the specimen

* First generation (UWO): mimicking the drainage pipe used in D4751
  * Main weakness: requires one rig for each pipe diameter
Recent Advances in Geotextile Filtration
Design: Pore Opening Size Measurement
using a Porometer or an Optical Tests

Stretching of the specimen

* Second generation: idealized stretching conditions

Image Analysis

Development conducted by Surface Science Laboratory at Western University (formerly UWO)

* Image acquisition
* Image processing
* Measuring relevant property (which one!)

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Image acquisition and processing

- Image acquisition
  - Minimum surface / number of openings
  - Image resolution
- Freeware software
  - ImageJ [https://imagej.nih.gov/ij/]
- Image processing
  - Separate ‘fibers’ from ‘openings’
  - Exclude stray yarns

Figure 5. Flowchart representing the image processing method used on IGS raw images.

Software used: ‘ImageJ’ (freeware) with Fiji plugin

- **Area:** Surface area of each pore.
- **Perimeter:** Length of the pore’s border.
- **Feret’s Diameter:** Longest distance between parallel lines around the pore.
- **Minimum Feret’s Diameter:** Shortest distance between parallel lines around the pore.
- **Major Ellipse Axis:** Length of the major axis of an ellipse fit to the pore.
- **Minor Ellipse Axis:** Length of the minor axis of an ellipse fit to the pore.
Reference value?

- A reliable reference opening size is needed for comparison with IOS
  - AOS (D4751, dry sieving)
  - FOS (CGSB 148.1 n°10, hydrodynamic sieving)

- Deviation inherent to the test procedure (stressed and relaxed) is higher for AOS than for FOS – even after exclusion of outliers.

- Hence FOS was considered as the reference properties for comparison with image opening size results.

- Conclusions made using FOS as a reference remain applicable to AOS, based on the observed correlation ($R^2=0.95$) between AOS and FOS for the circular knit geotextiles tested.
**Image analysis results**

- **Type**
  - Feret (major, minor)
  - Ellipse (major, minor)
  - Area-based
  - Perimeter-based

- **Percentile**
  - 95%
  - Actual
  - Normalized curve
  - 50%

**Properties offering the best correlation to FOS**

Best $R^2$ (~98%) noticeably obtained for:
- $d_{50}^f$: Mean Minor Feret Diameter
- $d_{50}^e$: Mean Minor Ellipse Diameter

Consistent with the concept of a spherical bead passing through the opening: limited by the minimum distance available
Further verifications

Determination of ‘O₅₀’, ‘O₉₅’?

* Percentage of the number of units?
* Percentage of the surface?
* Percentage of the volume?

Validation with the universal stretching rig (CTTG)

* Similar relation observed:
  * Min Feret diameter
  * Good correlation with O₅₀, O₅₀S, O₅₀V and d_mean
* Mean diameter ‘d_mean’ suggested
  * Convenience!
  * Less risks of errors
  * Frequently observed throughout the surface (in contrary to 95 percentiles)
Usefulness of optical results

- Provides extensive data on the shape and distribution of openings
- Meets and exceeds current manufacturing quality control needs
- Excellent correlation between “C*FOS” and the mean minimum diameters (Feret or Ellipse), with $R^2$ greater than 97%
- Consistent with the concept of a spherical bead passing through the opening
- For knitted geotextiles, there is a relation between FOS and AOS with a $R^2$ of ~0.95, hence AOS is also correlated to the optical test results.
- An experimental correction factor ‘C’ will be required if the intention is to estimate FOS and AOS (and other properties?) based on Image Opening Size

Practical considerations

- Optical test: MUCH quicker to perform than AOS of FOS – can be efficiently implemented in MQC at low cost
- Much less parameters need to be controlled (beads, etc)
- Proposed rig: stretching is better controlled + the test is non-destructive
- Standardization in progress
  - Not applicable to needle-punched. Other structures? Heat bonded? Woven?
  - The test report should provide a full characterization of the pores, i.e., the distribution of minimum and maximum diameters, and include a significant property, e.g., $d_{50}$
**Further presentations**

| Introduction | Eric Blond  
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Review of existing pore opening size measurement techniques, how reliable are ASTM D4751 and ISO 12956?</td>
<td>Eric Blond</td>
</tr>
</tbody>
</table>
| Innovative technique #1: porometer | Sam Allen  
| 1. Benefits of PSD and the porometer test for AOS determination | Melissa Medlin (TenCate) |
| 2. Experimental correlation between porometer and AOS tests | |
| Innovative technique #2: optical measurement | Eric Blond  
| 1. Assessment of the pore opening size of knitted geotextiles by image analysis | A-L Backes (Dupont) |
| 2. Application of optical measurements for MQC of heat-bonded geotextiles | |
| Q&A | |