Recent Advances in Geotextile Filtration Design: Pore Opening Size Measurement using a Porometer or an Optical Test
IGS Technical Committee on Hydraulics
April 26, 2022

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

EB CONSULTANT

1

1

Image Opening Size

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

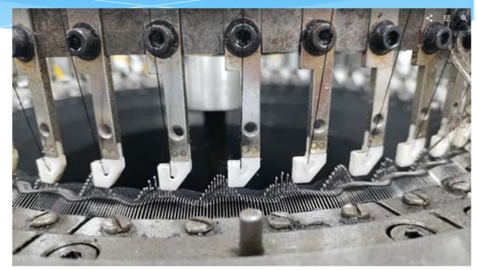
Recent Advances in Geotextile Filtration Design: Pore Opening Size Measurement using a Porometer or an Optical Tests – IGS Technical Committee on Hydraulics – April 26, 2022

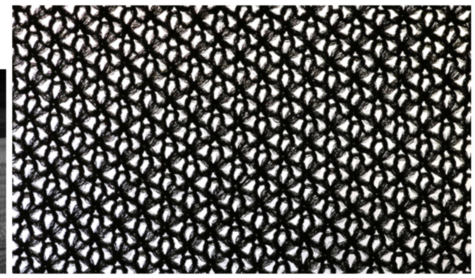
2

2

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



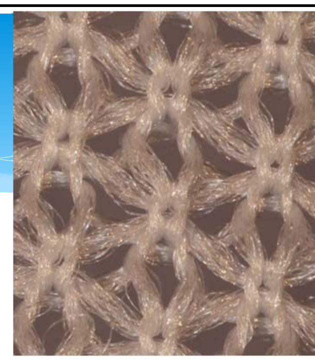


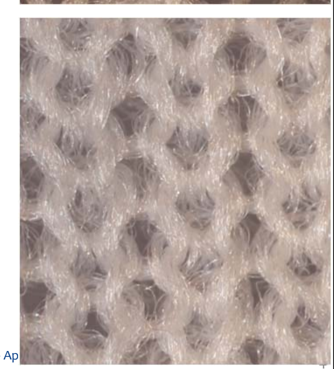
3

Typical knitted geotextiles

Typical structures complying to ASTM D6707:

* 2D: typical knitted geotextile
* 3D: tighter knitted geotextiles, with smaller opening sizes





4

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")

D4751 – 21

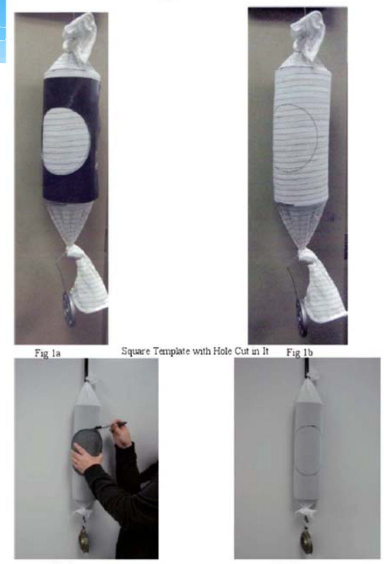


FIG. 1 Specimen Cutting Templates for Circular-Knitted Sock Geotextiles

Testing knitted geotextiles per ISO 12956 (wet sieving)

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

ISO/DIS 12956:2018(E)

Annex C
(normative)

Preparation of knitted socks for testing

Apply the knitted sock geotextile sample over the outside of the corresponding diameter of a 400 mm length of perforated tubing or reasonable facsimile having the same diameter as the pipe material for which the sock is intended.

Tie a knot in each end of the fabric so as to fully encase the pipe in the fabric.

Using the knot from one end of the fabric, suspend the geotextiles encased pipe vertically. Gently suspend a 1,125 kg weight from the bottom to ensure intimate contact with the perforated pipe. Allow the suspended pipe with weight to hang for 2 min.

Using a flexible 200 mm diameter round template as a guide, trace a circle on the surface of the fabric using an indelible marker

Apply a high-adhesion tape with a stiff backing on the exterior side of the line, while the specimen is still on the pipe.

Prepare a circular insert, made of a material that is flexible in its plane but non-compressible, i.e. a 1,5 mm HDPE geomembrane. This piece must have an inner diameter of ± 220 mm and an outer diameter of ± 230 mm.

Place this circular insert on the specimen and tape it as well so it is concentric with the 200 mm diameter circle drawn on the sample. Care must be given to not apply tape inside the 200 mm line.

The geometry of the knitted sock has been secured. Cut the test specimen at least 10 mm behind the plastic insert and flatten it for insertion in the clamping system

Perform the test as specified in the standard.

In addition to the requirements of Section 8, report that:

— the product was tested in as applied conditions' as per Annex C

— diameter of the pipe used for preparation

The Figure C.1 shows the different steps of the preparation.

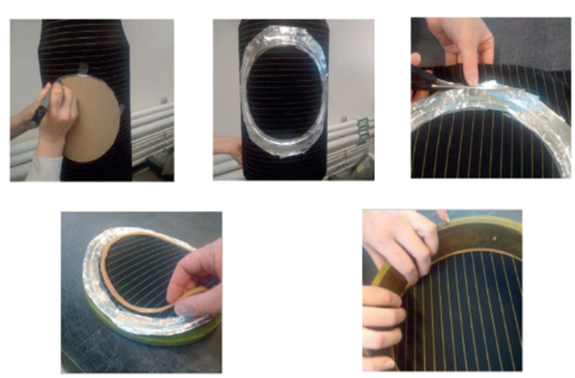


Figure C.1 — Different steps of preparation

Testing knitted geotextiles per D4751-B (Porometer) (equ. to D6767)

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)?

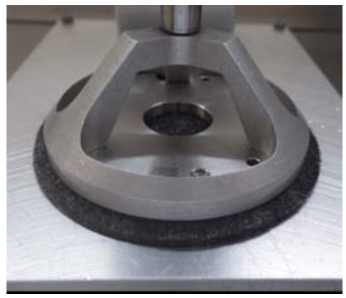
14. Calculation of the O95 Opening Size Value

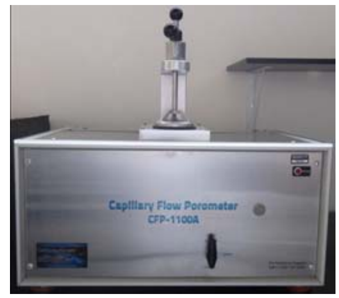
14.1 The calculation of opening size is based on the following equation:

$$O = C/P \quad (1)$$

where:

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



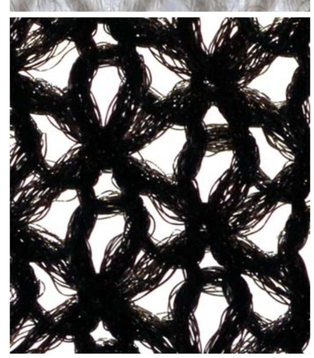


Solution considered

- 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!



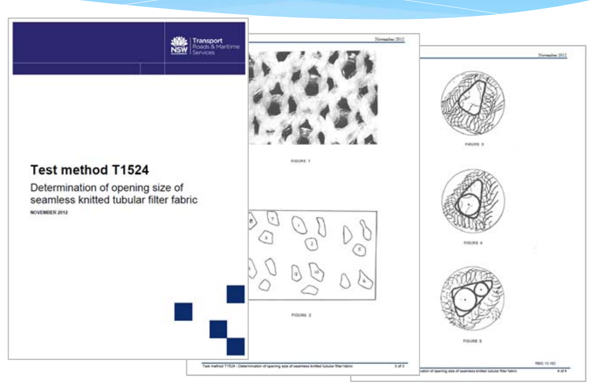
Solution developed

* 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)

CARRIFF ENGINEERED FABRICS CORPORATION

SAGEOS Division du / of GroupeCTTGroup

SURFACE SCIENCE WESTERN

Key results or a R&D Collaborative project

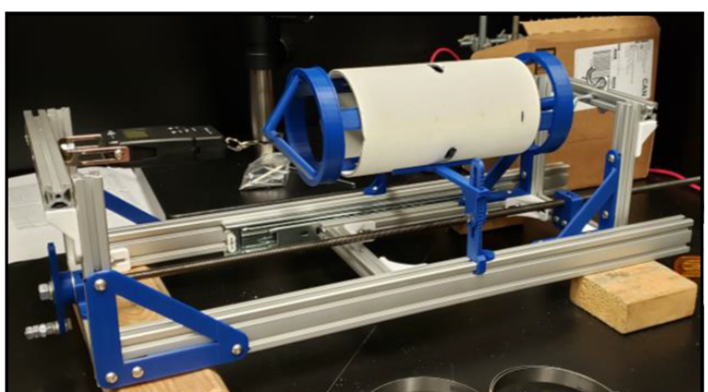
Tested products:	**Carriff knitted geotextiles**
Opening size tests:	**Performed by CTT Group**
Optical tests:	**Developed by Western University (formerly UWO)**
	Repeated by CTT Group

11

11

Stretching of the specimen

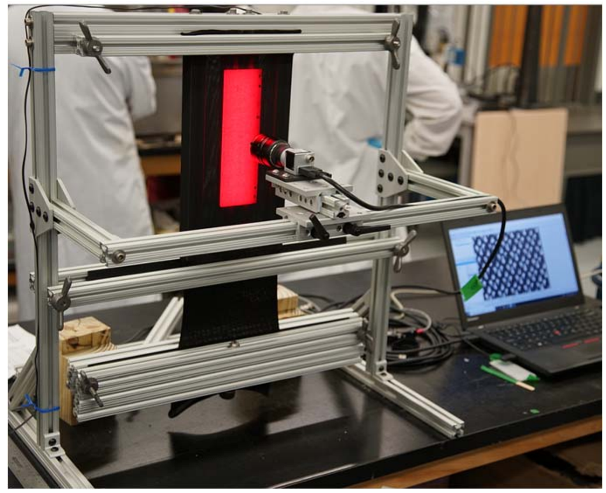
- First generation (UWO): mimicking the drainage pipe used in D4751
  - Main weakness: requires one rig for each pipe diameter



12

Stretching of the specimen

* Second generation: idealized stretching conditions



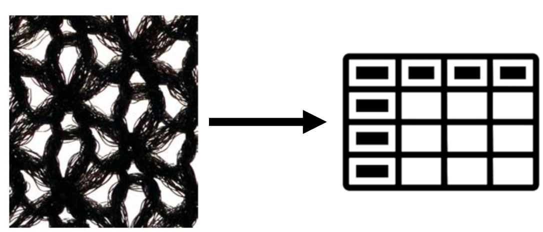
13

Image Analysis

SURFACE SCIENCE WESTERN

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

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



14

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

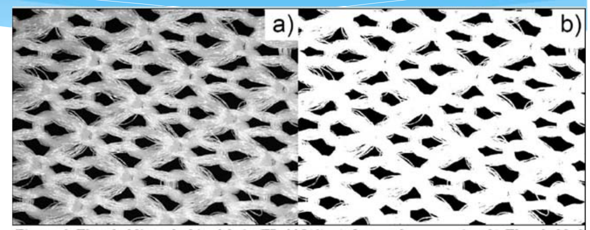


Figure 6: Thresholding of white fabric (FL-00512). a) Greyscale conversion. b) Thresholded image with threshold of 70 (notice each yarn extending within the pores can be seen on both sides).

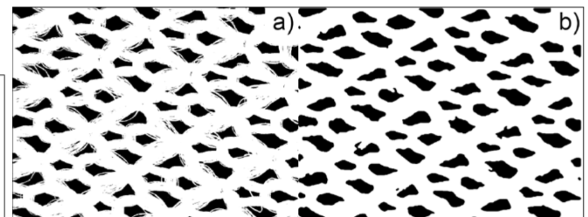


Figure 7: Removal of stray yarn. a) Thresholded image. b) Image after "Close-" and "Open" operations with appropriate settings.

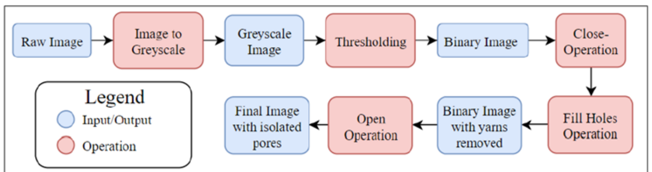
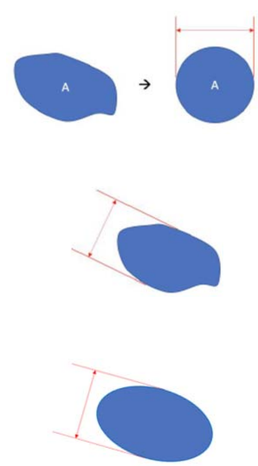


Figure 8: Flowchart representing the image processing method used on IOS raw images.

Image acquisition and processing

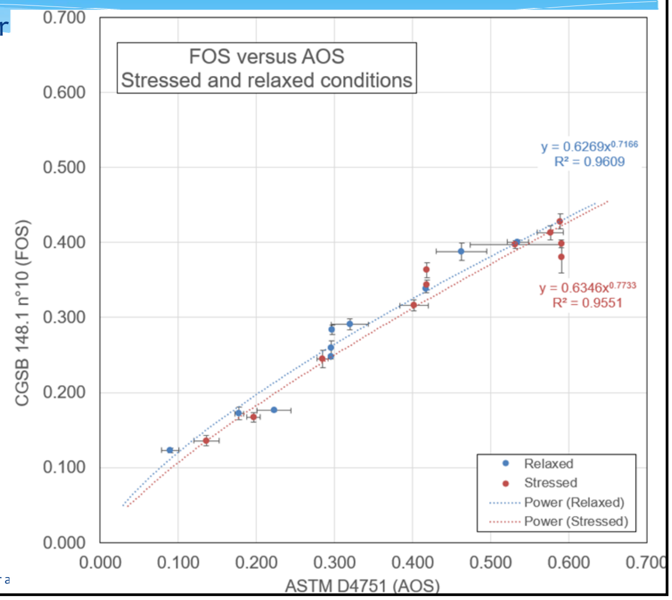
Software used: 'ImageJ' (freeware) with Fiji plugin

- 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 (~ standard deviation) 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.



Recent Advances in Geotextile Filtration Design: Pore Opening Size Measurement using a Porometer or a

17

Recent Advances in Geotextile Filtration Design: Pore Opening Size Measurement using a Porometer or an Optical Tests – IGS Technical Committee on Hydraulics – April 26, 2022

Image Analysis results

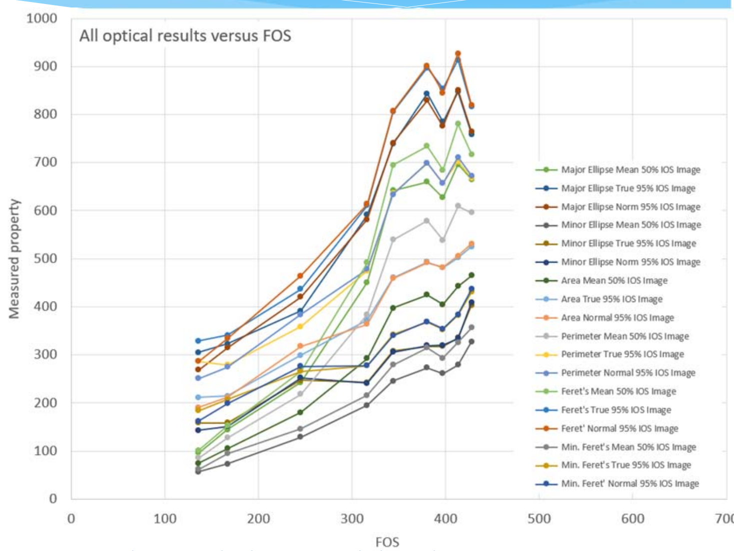
Comparison of optical properties with FOS

18

18

Image analysis results

* Type
  * Feret (major, minor)
  * Ellipse (major, minor)
  * Area-based
  * Perimeter-based
* Percentile
  * 95%
    * Actual
    * Normalized curve
  * 50%



Recent Advances in Geotextile Filtration Design: Pore Opening Size Measurement using a Porometer or an Optical Tests – IGS Technical Committee on Hydraulics – April 26, 2022

19

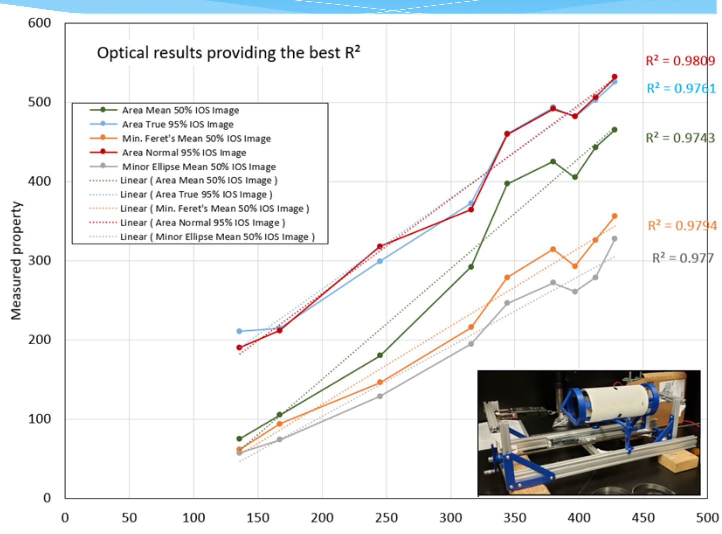
19

Properties offering the best correlation to FOS

Best R^2 (~98%) noticeably obtained for:

* d^F_{50}: Mean Minor Feret Diameter)
* d^F_{50}: Mean Minor Ellipse Diameter

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



Recent Advances in Geotextile Filtration Design: Pore Opening Size Measurement using a Porometer or an Optical Tests – IGS Technical Committee on Hydraulics – April 26, 2022

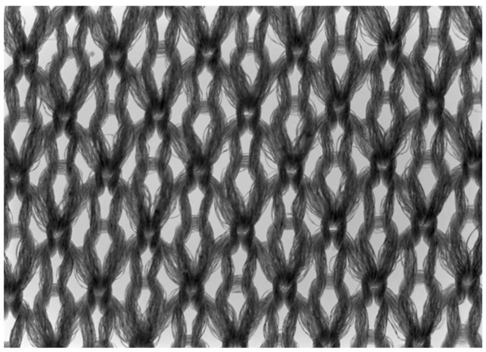
20

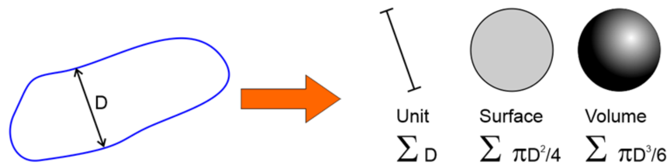
20

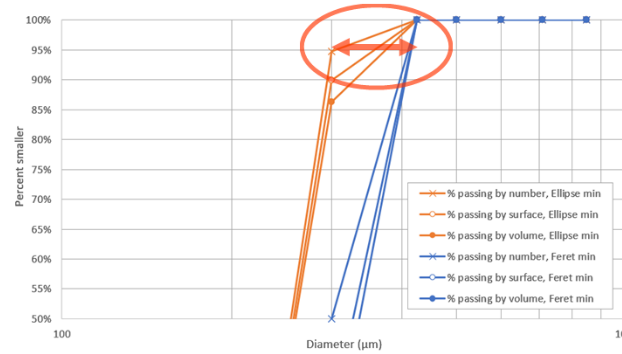
Further verifications

Determination of ‘O_{50}’, ‘O_{95}’?

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





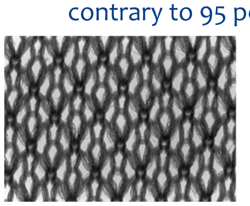


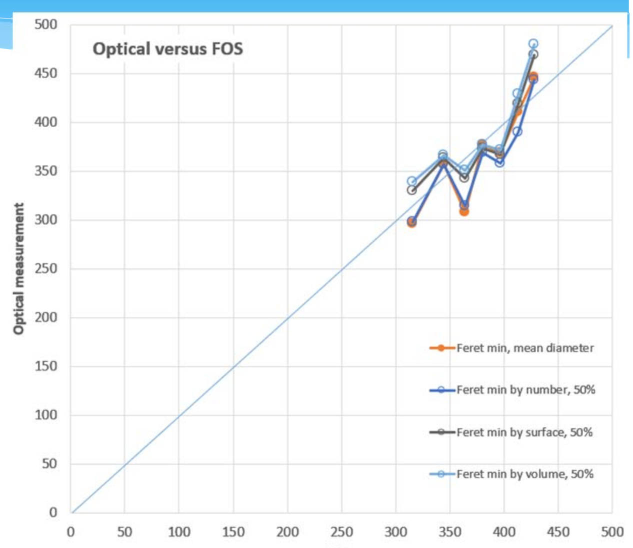
Recent Advances in Geotextile Filtration Design: Pore Opening Size Measurement using a Porometer or an Optical Tests – IGS Technical Committee on Hydraulics – April 26, 2022 21

21

Validation with the universal stretching rig (CTTG)

- Similar relation observed:
  - Min Feret diameter
  - Good correlation with O_{50u}, O_{50S}, O_{50v} and d_{mean}
- Mean diameter ‘d_{mean}’ suggested
  - Convenience!
  - Less risks of errors
  - Frequently observed throughout the surface (in contrary to 95 percentiles)





Recent Advances in Geotextile Filtration Design: Pore Opening Size Measurement using a Porometer or an Optical Tests – IGS Technical Committee on Hydraulics – April 26, 2022 22

22

Usefulness of optical results

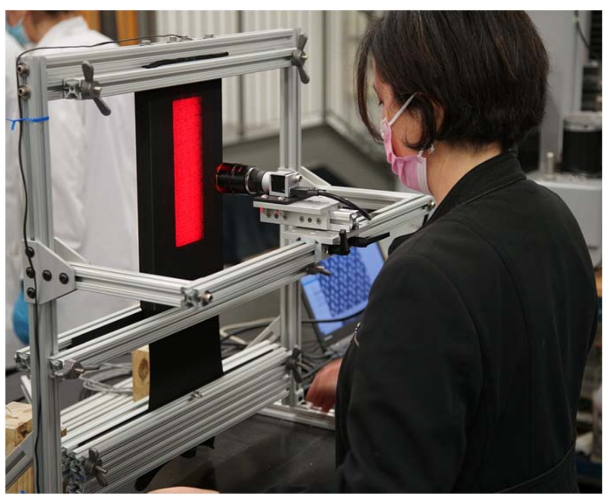
* Provides extensive data on the shape and distribution of openings
  * Meets and exceeds current manufacturing quality control needs
* Excellent correlation between "C*FOS" and the mean minimum diameters (Feret or Ellipse), with R^2 greater than 97%
  * Consistent with the concept of a spherical bead 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

Recent Advances in Geotextile Filtration Design: Pore Opening Size Measurement using a Porometer or an Optical Tests – IGS Technical Committee on Hydraulics – April 26, 2022 23

23

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^F_{50}



Recent Advances in Geotextile Filtration Design: Pore Opening Size Measurement using a Porometer or an Optical Tests – IGS Technical Committee on Hydraulics – April 26, 2022 24

24

Further presentations

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