

LINKING DESIGN WITH SPECIFICATION OF GEOTEXTILES

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INTRODUCTION

Geotextiles usually make up a fraction of the cost of an engineered structure and are primarily incorporated in the stabilisation or strengthening measures in the foundation or base of the structure. As such, the design of these geotextile used in any structure is critical to the long term life of the structure. While geotextile design methodology is reasonably well understood the correct specification of the geotextile is often overlooked or poorly understood and implemented. A poorly constructed specification will often result in installation of a geotextile which bears little or no resemblance to the geotextile which was originally designed. This often leads to poor performance and associated high maintenance of the structure and at worst failure.

Many of the geotextile test methods have been adapted from the general textile industry and can not be directly related to the engineering functions that geotextiles are designed to perform. Different test methods throughout this document are described as either an Index test or a Performance test. Index test results are obtained quickly, with good reproducibility, which permits the comparison of one product to another and are ideally suited to the manufacturing quality assurance process. Performance tests allow direct assessment of the likely in-situ interaction between the soil and a geotextile.

Therefore, understanding the intricacies of the test methods and how they relate to the application of the geotextile is the key to the project. This document will attempt to improve the understanding of the relevant test methods and their application.

Understanding the test method alone is not sufficient to ensure the correct product is supplied. The designer must understand how the information presented in manufacturer's data sheets is compiled and how this relates to the product supplied to site. It is critical that designers can interpret individual test results obtained as either Manufacturing Quality Assurance (MQA) or Construction Quality Assurance (CQA) as failure to correctly interpret results can lead to incorrect acceptance or rejection of products supplied.

In an attempt to cover all the issues raised above the following topics will be discussed in some detail

- Relating function to test method
- Test methods overview
- Data sheet interpretation
- Conclusion

2 RELATING FUNCTION TO TEST METHOD

When specifying geotextiles, a number of geotextile characteristics must be considered. The German Association for Water Resources and Land Improvement (DVWK) produced the following table to assist engineers to define the application and most suitable parameters to be considered.

	Sub Soil Drains	REVETMENTS	Reinforcing
Mechanical filter effectiveness	①	①	2 (3)
Water permeability	①	①	2 (3)
Durability	①	①	①
Friction Soil/geotextile	4-2	①	①
Impact resistance	2-3	①	2
Adaptation to uneven surfaces	2	①	2
Tensile strength	4	2	①
Tensile strain	3	2	①
Creep	4	4-2	①

How the parameters listed in the table above are related to geotextile properties is as follows:

2.1 MECHANICAL FILTER EFFECTIVENESS

- Thickness (mm) AS3706.1 – Measured under 2kPa pressure.
- Pore Size (μm) AS 3706.7 – Generally defined as EOS, will retain 95% of particles of this size or greater. Measured under dry sieving conditions.
- EOS must be specified to suite the grading curve of the material in contact with the geotextile.

2.2 WATER PERMEABILITY

- Through Flow ($\text{l/m}^2/\text{s}$) AS3706.9 – Measures the volume of water, which will pass through the geotextile for a given time at a given head of pressure.
- Permeability (m/s) AS3706.9 - Measures the volume of water, which will pass through the geotextile of a certain thickness for a given time at a given head of pressure.
- The higher the values above the better, as both will reduce in the long term due to particle blocking or clogging. Lower values may cause build up of pore water pressure.

2.3 DURABILITY

- UV Resistance (%) AS3706.11 – Measures the strength loss after 672 hours due to UV radiation, 50% Strength must be retained for drainage and separation geotextiles, 75% strength must be retained for more exposed conditions.
- Unfortunately this test is difficult to translate into real time values; test should be used to compare the UV resistance of various geotextiles. This method specifies a xenon arc apparatus for the light source.

2.4 FRICTION

- Interface friction (deg) ASTM D5321-97 – Measures the interface friction between soil and geotextile, or geotextile and geosynthetic residual interface friction values should be used.
- Makes use of a minimum of a 300 mm x 300 mm shear box to reduce edge effects. This parameter is very important when a geotextile is laid against a slope with a smooth firm surface.

2.5 IMPACT RESISTANCE

- Drop Cone D₅₀₀ (mm) AS3706.5 – Measures the size hole created when dropping a cone from a fixed height of 500mm.
- Minimal puncturing of the geotextile should be allowed for filtration applications, as an increase in the quantity or size of holes will reduce filtration capability of the geotextile.

2.6 ADAPTATION TO UNEVEN SURFACES

- CBR Elongation (%) AS3706.4 – Measure the elongation at failure of geotextile when tested in the CBR plunger test.
- Evaluates the three dimensional conformability of the geotextile when deformed around a 50mm Ø plunger; the greater the elongation at failure the more likely the geotextile is to adapt to uneven surfaces.

2.7 TENSILE STRENGTH

- Tensile Strength (kN/m) AS3706.2 – Measures ultimate tensile strength of geotextile.
- Geotextile should be strong enough to prevent tearing or significant deformation during installation. Geotextile is tested in both the machine and cross-machine directions.

2.8 TENSILE STRAIN

- Tensile Strain (%) AS3706.2 – Measures elongation in a single plane.
- Elongation is a function of damage susceptibility i.e. as the elongation of the geotextile increases the risk of damage is reduced.

2.9 CREEP

- Creep has been excluded from the scope of this review.

3 TEST METHOD OVERVIEW

This summary is intended to provide the reader with a quick guide to Australian Standard test methods.

3.1 AS3706.1-00 MASS & THICKNESS

- Index Test – as it does not take into account soil geosynthetic interaction.
- Both tests are a measure of basic physical properties of a geotextile. Geotextiles are specified on filtration and mechanical properties, with mass and thickness used for guidance information in comparing geotextiles.

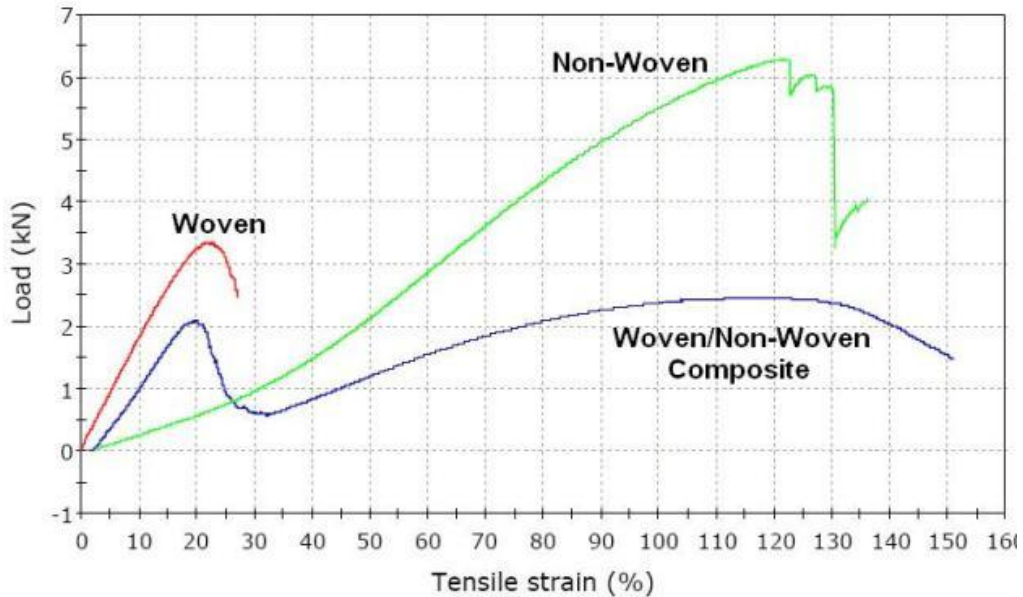
Units:	g/m ² and mm thickness under 2 kPa load
Specimen size:	and thickness is a sample under a 2500 mm ² pressure foot
Number of specimens:	10 per test type
Similar Standards:	ASTM D5199 ISO 9863-1 or -2 (single layer or multi layer)

3.2 AS3706.2-00 WIDE STRIP TENSILE STRENGTH

- Index Test – as it does not take into account soil geosynthetic interaction.

The wide width tension test is used to determine the predicted working stress/strain range of a geotextile. This test simulates the total load which the geotextile is subjected to whilst involved in soil reinforcement. Being designed specifically for geotextile testing (from the narrow strip textile test) this test reduces the adverse effects of necking on the test specimen during testing, and is used specifically for civil products.

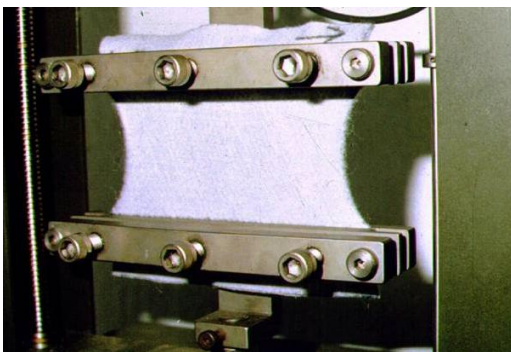
Primarily used to specify geotextiles used in soil reinforcement applications, in these applications the relationship between geotextile strength and elongation is critical. Typical strength vs. strain (elongation) relationship between various generic geotextiles is shown below.



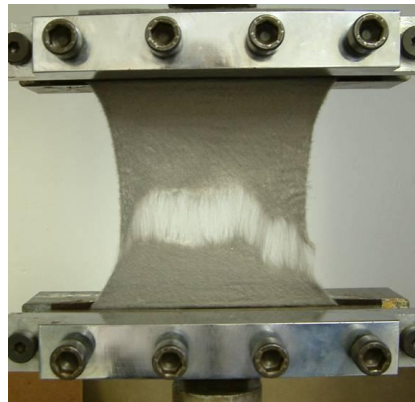
A wide fabric strip (200 mm wide) is fastened between two jaws 100 mm apart and put under tension at a constant rate of extension. The whole width of the specimen is gripped with both machine and cross-machine directions tested.

Units:	kN/m
Specimen size:	200 mm x 250 mm
Number of specimens:	10 per direction
Test speed:	20 mm/min
Gauge length:	100 mm
Similar standards:	ASTM D4595 ISO 10319 BS EN ISO 10319 BS 6906.1

Note: When comparing results obtained with the above mentioned standards, the test speeds and calculated moduli may be different. However, results reported as mean or typical (kN/m) are comparable.



Wide Width Strip – Tensile



Failed Wide width strip specimen

3.3 AS3706.3-00 TRAPEZOIDAL TEAR STRENGTH

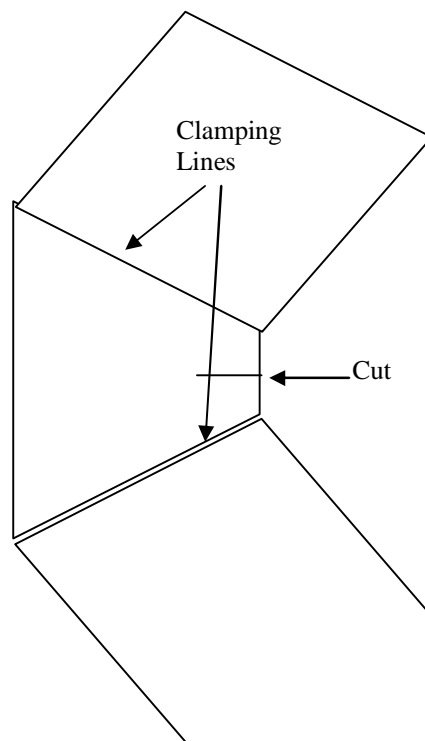
- Index Test – as it does not take into account soil geosynthetic interaction, machine & cross-machine are tested.

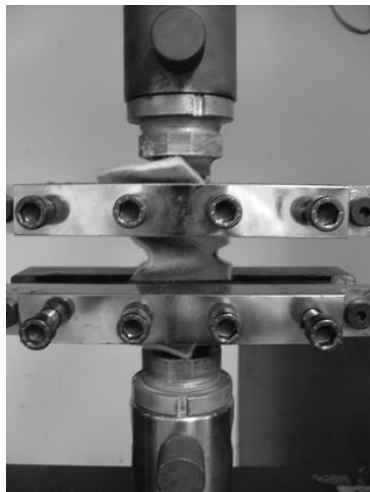
A tear in the geotextile can propagate when it is subjected to tension and may result from puncturing caused by:

- the geotextile failing to fully conform to the profile of aggregates or undulating ground.
- installation damage.

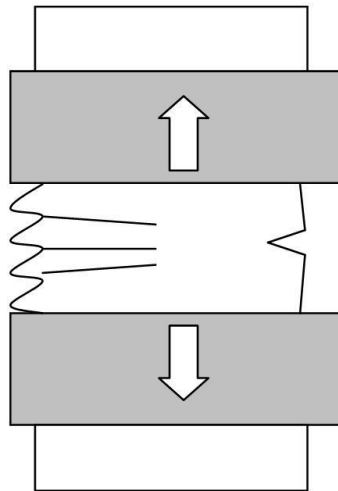
This test derives its name from the trapezoidal clamping lines stencilled across the fabric. Under a constant rate of extension, the fabric tears from a pre-initiated cut in the specimen across the width of the fabric. The side with the cut is held taut in the clamps; the trapezoidal clamping lines are made to be parallel and clamped in the jaws. This has the effect of opening the cut and leaving the other side of the specimen slack in the jaws.

Units:	Newtons (N)
Specimen size:	75 x 200 mm
Number of specimens:	10 per direction
Cut length:	15 mm
Test speed:	300 mm/min
Gauge length:	25 mm
Similar Standards:	ASTM D4533 ISO 9073.4





Trapezoidal Tear



Failed Specimen

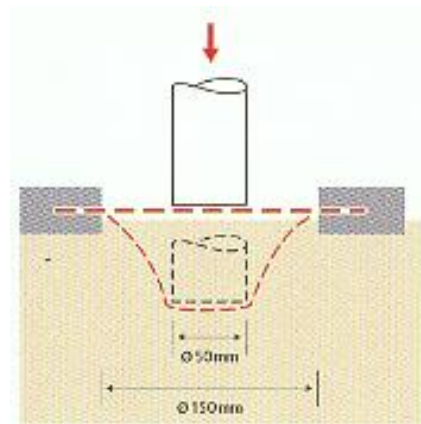
3.4 AS3706.4 CBR BURST TEST

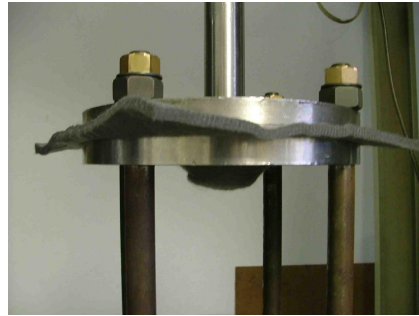
- Performance or Index – depending on the site conditions

A CBR test simulates bursting/puncturing a fabric, by applying a load normal (perpendicular) to the plane. This test method is designed to simulate fabric bursting caused by aggregate being forced through a geotextile under a load such as heavy equipment.

A 50 mm diameter plunger with a flat face base is used and load is applied vertically at a constant rate until failure occurs.

Units:	Newton (N)
Specimen size:	Ø 150 mm
Number of specimens:	10
Plunger:	Ø 50 mm
Test Speed:	50mm/min
Similar Standards:	BS 6906.4
	ASTM D6241
	ISO 12236



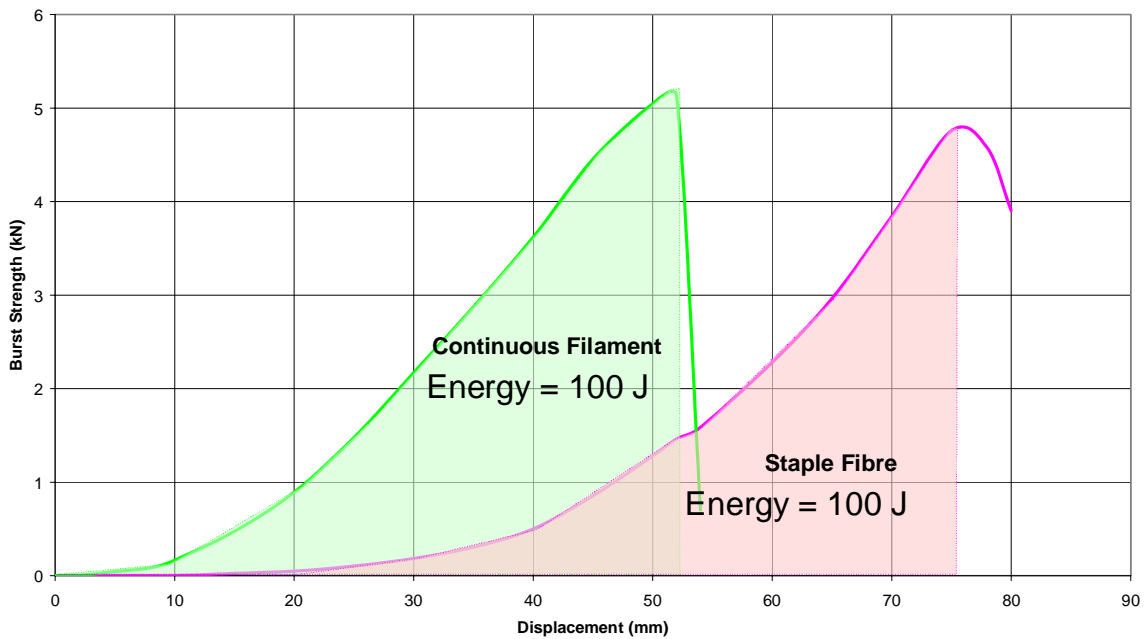


CBR Text side view



Failed Specimen

Typical CBR Curves for Nonwovens



3.5 AS3706.5 DROP CONE PUNCTURE TEST

- Performance test – as it attempts to mimic construction damage (unfortunately test method is vague and results in a wide distribution of results).

This test method is specific to civil applications. This test was developed specifically for geotextiles and is not a standard test for industrial textile products. The drop cone test simulates the damage that may be caused to a geotextile by a falling rock or similar object.

- A 1 kg cone is dropped from a specified height and the puncture size measured.
- Puncture resistance is measured in terms of the standard puncture diameter (d_{500}) and the puncture resistance (h_{50}).

- The d_{500} measurement is defined as the puncture (hole) diameter (in millimetres) made when the cone is dropped from a height of 500mm.
- The h_{50} is the theoretical drop height (in millimetres) required to obtain a puncture diameter of 50mm.

Units:	mm
Specimen size:	Ø 150 mm
Number of specimens:	10
Cone weight:	1 kg
Cone angle:	45°
Max. cone Ø:	50 mm
Similar Standards:	BS EN 918 ISO 13433



Drop weight test –
1kg sharpened cone



Measuring hole diameter



Failed specimen

The Australian test method has three areas of weakness

3.5.1 Determination of hole size

The method of measuring the hole-size is very subjective and results in large variations in data between laboratories depending on the method adopted by the given laboratory. This is particularly problematic with high elongation nonwoven geotextiles which deform substantially of impact and as a result make accurate measurement very difficult (the example below shows the significant differences in end results when measurements are out by as little as 0.5 mm)

The test method states that the hole size is measured as follows:

- 10(e) Insert the measuring cone and allow it to come to rest under its own weight with its axis vertical. Do not push, twist or allow it to fall over.

NOTE: For highly extensible geotextiles it may be necessary to tilt the cone to enable a reading to be made

- 10 (f) immediately mark or hold a marker on the lowest point of contact between the measuring cone and the geotextile to enable a reading to be made.

Based on the requirements above, there are two points which lead to inaccurate readings and the high inter-laboratory variations

1. Leaning the measuring cone over makes it impossible to accurately define contact point prior to leaning the cone over.
2. The thickness of the object used to hold or mark the lowest point can have a considerable influence on the result i.e. a person’s finger vs. a fine line marker pen.

It is important to note that the European drop cone test method (ISO 13433) does not allow the cone to be leaned over and the hole size is measured from the bottom of the sample which eliminates measuring errors.

3.5.2 Calculation of Standard puncture diameter (d_{500})

In an attempt to create an equivalent value over a range of geotextile masses the standard allows variable drop heights and questionable formulas to attempt to return actual values to a single theoretical drop height. It is not clear that a single formula can correlate a large range of geotextiles with vastly different stress vs. strain behaviour.

The test method states that the hole size is measured as follows:

hole >15 mm diameter	result is acceptable
if hole <15 mm	Increase drop height and apply formulas below

Four standard drop heights are acceptable and are as follows;

Drop Height	Conversion to d_{500}
250 mm	$d_{500} = 1.6 d_{250}$
750 mm	$d_{500} = 0.76 d_{750}$
1000 mm	$d_{500} = 0.62 d_{1000}$
1500 mm	$d_{500} = 0.47 d_{1500}$

3.5.3 Calculation of puncture resistance

The values for the d_{500} calculated above are then applied to a second formula the result of which indicates the theoretical drop height of a 1kg cone to create a 50 mm hole in the geotextile.

The test method states that the drop height must be calculated as follows:

$$h_{50} = 500 (50/d_{500})^{1.47}$$

The output from this formula is highly variable as small differences in the d_{500} values can have a significant impact of the results. The examples below show the gravity of the problem when a small variation in d_{500} is imputed into the formula (these figures are actual results on the same product tested by two different laboratories)

Examples

Geotextile A

Laboratory 1: $d_{500} = 11$ mm, hence $h_{50} = 4630$ mm

Laboratory 2: $d_{500} = 13$ mm, hence $h_{50} = 3622$ mm

a 1008 mm variation

Geotextile B

Laboratory 1: $d_{500} = 7$ mm, hence $h_{50} = 8998$ mm

Laboratory 2: $d_{500} = 8$ mm, hence $h_{50} = 7394$ mm

a 1604 mm variation

Variations in reported results of up to 40% have been documented!

3.6 AS2001.2.3B GRAB TENSILE TEST

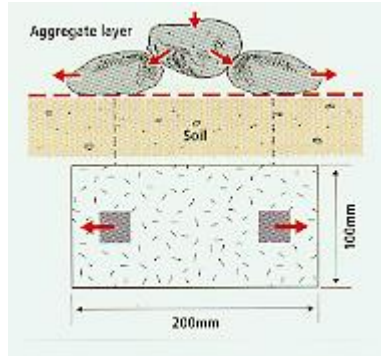
- Index test - as it does not take into account soil geosynthetic interaction.

The purpose of the grab test is to examine the behaviour of fabrics between local stresses. Thus, this test determines the breaking load and elongation of the fabric by simulating stones 'grabbing' the geotextile, which is 'localised' in-plane tension.

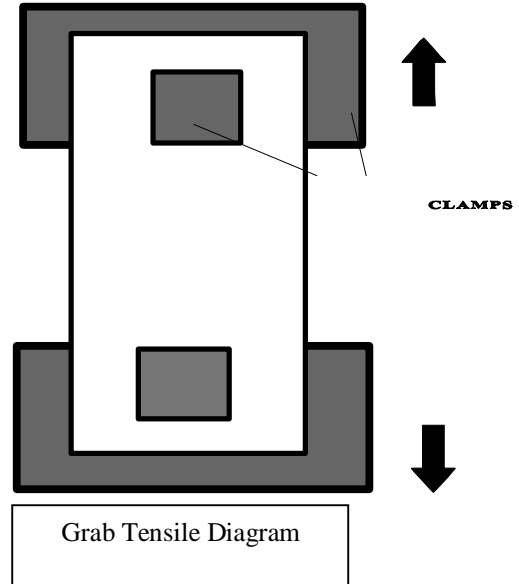
The textile is held between two jaws of different sizes, therefore only part of the test specimen is gripped in the clamps. The fabric tends to wrap or grab the smaller jaw, hence the name. Both machine and cross-machine directions are tested.

Units:	Newtons (N)
Specimen size:	100 mm x 200 mm

Number of specimens: 10 per direction
 Test speed: 300 mm/min
 Gauge length: 75 mm
 Similar Standards: ASTM D4632



Use in application



3.7 AS3706.7 PORE SIZE TEST – DRY SIEVE (EOS)

- Performance test – as it measures the size of particles will pass through the geotextile.

Geotextiles are often used as filters in civil applications, hence the size of the pores are important. An Equivalent Opening Size test (or EOS) is used to measure the pore size.

EOS (O₉₅): Equivalent Opening Size; the sand particle size for which 95% by mass would be retained on the geotextile.

50 g of graded sand (specific particle size range) is placed on the surface of the fabric and shaken mechanically for 10 minutes. The mass of the sand passing the fabric is recorded. This is repeated with smaller sized sand until more than 50% of the sand passes the fabric.

Units: μm
 Number of specimens: 5
 Similar Standards: ASTM D4751

Note: The American Standard stated above determines the pore size but uses a different method. It calculates the amount of glass beads passing through the fabric and is reported as the Apparent Opening Size (AOS). The EOS and AOS results are not exactly comparable.



Pore Size Analysis



3.8 AS3706.9-01 PERMITTIVITY TEST

- Index test - as it does not take into account soil geosynthetic interaction or confining stress.

Geotextiles can be used as both filters and drains, hence, water must be allowed to flow freely through the fabric. A permittivity test is used to measure the perpendicular water flow through the geotextile (normal to the plane) and is predominantly a Civil test.

Definitions:

- Permittivity - the flow rate of water for a known thickness of material. This is the measurable part of the test method, and is recorded in s^{-1} .
- Permeability - is a measure of how well a material will allow a liquid to pass, and is related to the structure of the material. Therefore material that is created the same way, even though it may be of different thicknesses, will have a similar permeability. This is a theoretical number based on Darcy’s law and derived from the permittivity.
- Flowrate - is calculated from the permittivity when head height and area are factored in. The flowrate is the volume of flow per unit area per unit time, generally under a 100 mm water head. (in $l/m^2/s$).

Units:	s^{-1}
Number of specimens:	5
Flowrate @ Head:	100 mm
Similar Standards:	ASTM D4491 ISO 11058

Note: Both the AS and ASTM standards calculate Permittivity, however they use different methods to do so. The Australian Standard also calculates an estimate of permeability, using an average thickness value. This may also be performed in the American method, although permeability is not a required calculation for this standard.

4 DATA SHEET INTERPRETATION

The interpretation of data shown on the data sheets of various suppliers can vary considerably depending how the values are presented. For example the difference between typical or mean results and MARV values can be significant and often during specification and or adjudication these values are either not understood or misinterpreted. It should be noted that most geotextile suppliers present typical values on the published data sheets.

This poses a number of key questions that anyone specifying or buying geotextiles should be aware of:

- When the data shown on product specification sheets has ‘typical’ values, what does that mean?
- When you purchase or specify a geotextile with particular criteria in mind, how much variation in the product do you expect?
- How do you check that the product which is delivered to site meets specification?
- How do you define what is acceptable so that there is no argument between the parties involved in the project?
- Are you getting what you paid for?

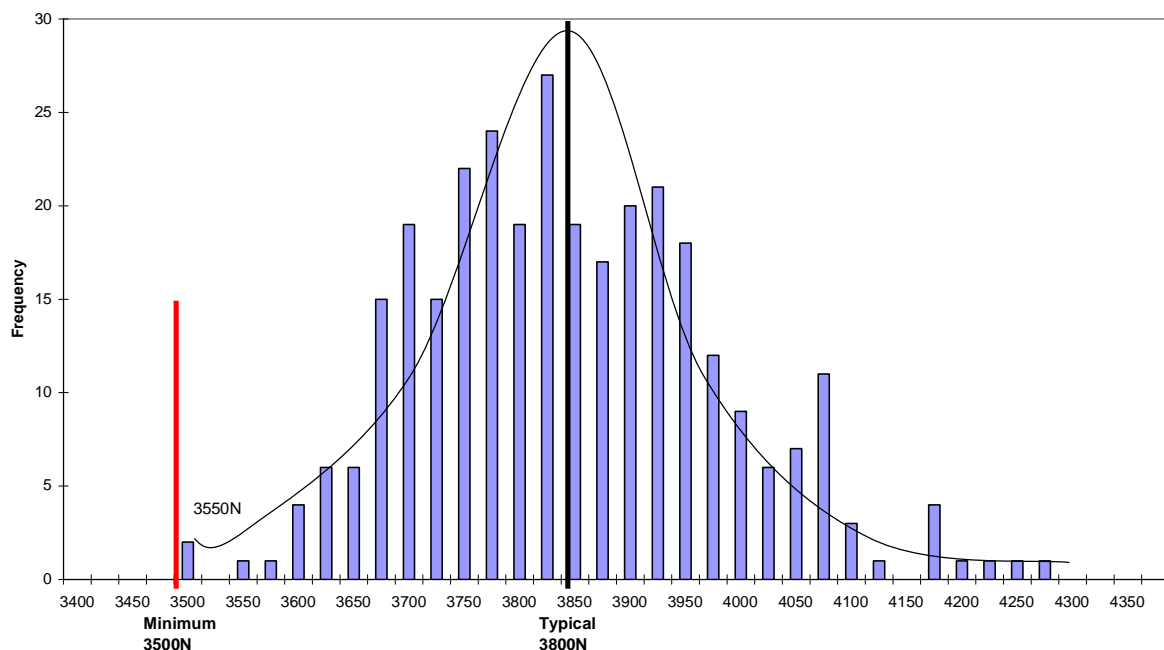
These questions can be important because geotextiles (like other manufactured goods) can be variable and the test methods used to evaluate them can also be variable.

There is a need to develop a clear understanding of the variability and the terms which can be effectively used to define a product parameter within that variability. These terms can be applied to a wide range of parameters including unit mass, tensile properties, bursting strength and even hydraulic properties.

4.1 TYPICAL AND MINIMUM

More often than not ‘typical’ values will be an indication of an average or mean value, but it could mean a value that the manufacturer hopes to achieve given favourable conditions. A mean value will imply that 50% of the product will typically exceed this value and 50% will typically not meet this value.

On the other hand a minimum value will mean that 100% of specimens will exceed this value. This is certainly clear and precise, but might be considered a little harsh for a variable product and variable test methods. It might also be wasteful in that the bulk of the product will exceed the parameter by a large margin. Figure 1 illustrates the relationship between the typical (or mean) value and the minimum value for a grade of geotextile.



Typical Distribution of CBR Results

In order to overcome this problem, the international trend has been to adopt a statistical approach, which provides a high level of confidence in the products performance and allows meaningful quality control testing on site. Details of the determination of these values are provided below.

4.2 STATISTICAL ANALYSIS

Geotextile test results are expected to follow the pattern of a normal distribution curve or ‘bell’ curve, and they can be effectively defined by the statistical terms that can be derived from a normal distribution of data.

Australian Standards AS 3705 and AS 3706.1 give a good outline of statistics as they apply to geotextiles. They define the mean and standard deviation (SD) as well as other terms and give guidance on sampling and populations. Knowing the standard deviation helps create a more accurate picture of the distribution along the normal curve. A smaller standard deviation represents a data set where scores are very close in value to the mean. A data set with a larger standard deviation has scores with more variance. In simple terms the larger the standard deviation the greater will be the variability of the product.

However many people find this a little complex and prefer to look at something like the 5th percentile or MARV values.

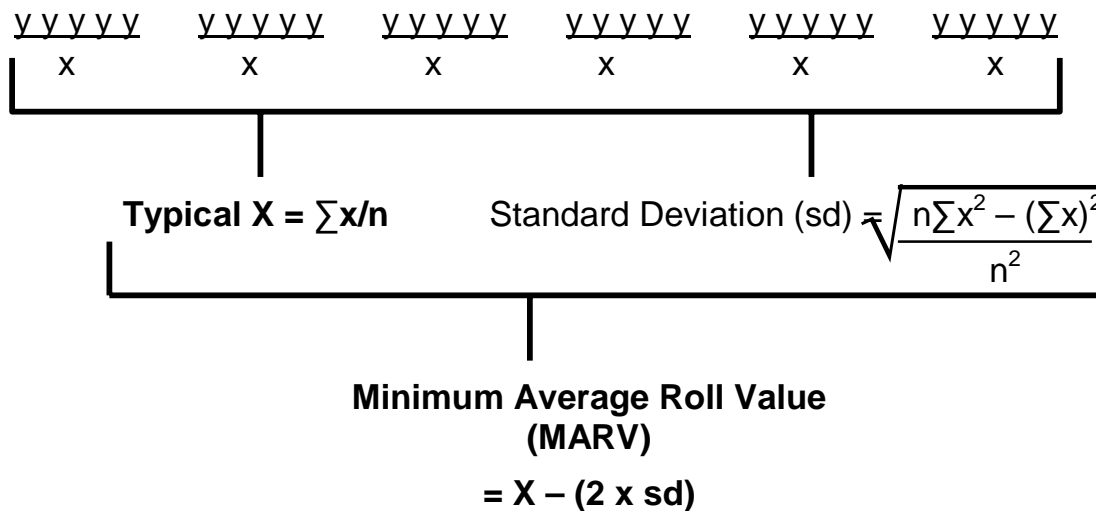
4.3 5TH PERCENTILE (P5)

P5 is a statistical derivation which was introduced in Australia some years ago, but for reasons unknown has not been widely adopted. For any distribution of data it is defined as the value represented by the mean less 1.645 standard deviations. Mathematically it is implied that 95% of the tested specimens will meet this value.

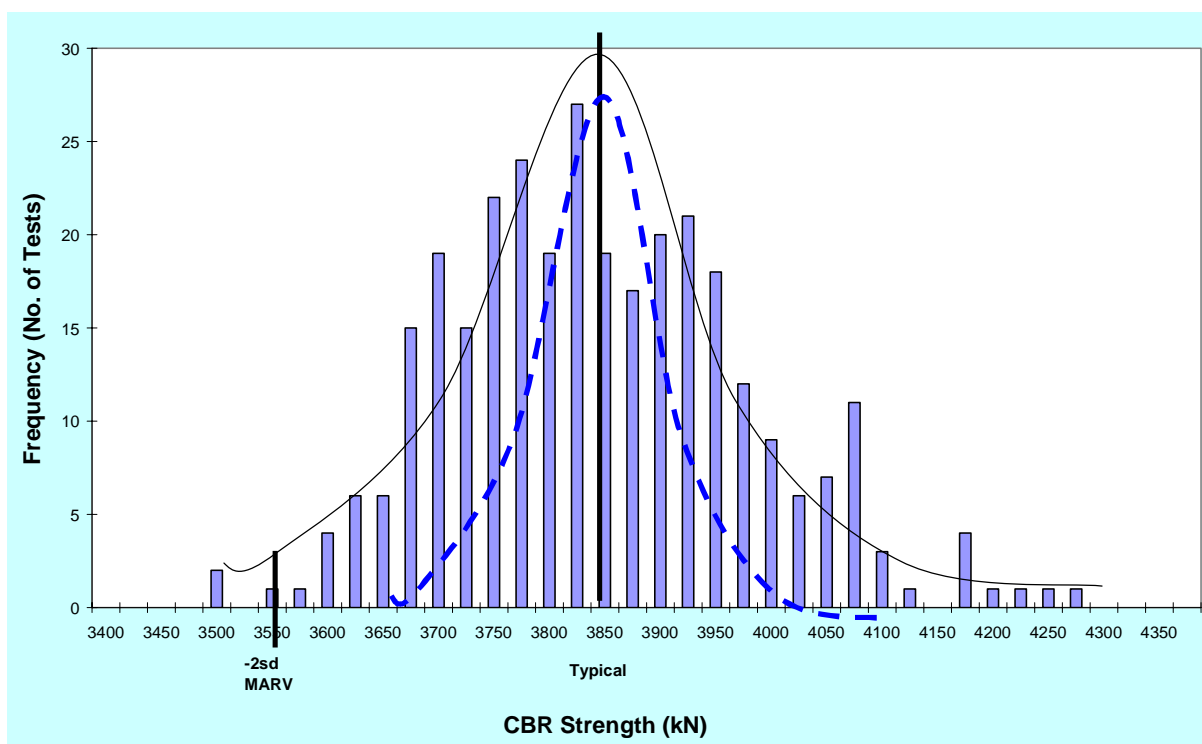
4.4 MINIMUM AVERAGE ROLL VALUE (MARV)

MARV is a statistical derivation which was introduced in the USA and is growing in usage around the world. For any distribution of data it is defined as the value represented by the mean less 2 standard deviations. Mathematically it is implied that 97.5% of the tested specimens will meet this value.

The calculation of MARV is as follows:



The figure below, shows why specification of MARV values provide the designer with a far greater level of confidence, than when specifying typical or mean values. Both geotextiles have the same typical value however, due to different manufacturing standards / methods, the variation in MARV values is significant and ultimately the higher quality product is preferable.



Comparison of two manufacturer's results

5 TESTING AND CONCLUSION

5.1 LABORATORY TESTING FOR MQA (MANUFACTURING QUALITY ASSURANCE)

Manufacturers provide test summaries or certificates as a part of MQA for geotextiles. Testing frequency for each method will vary with the test method type, test cost and availability of test equipment or laboratory services to the manufacturer. Not all geotextile tests make good routine quality control tests in manufacturing and may be out-sourced periodically.

It is important when specifying MQA requirements for a geotextile that communication is held with the supplier as to what methods are available and at what frequency does the testing occur, usually reported in so many tests per thousand(s) of m² of geotextile produced.

5.2 LABORATORY TESTING FOR CQA (CONSTRUCTION QUALITY ASSURANCE)

Construction Quality Assurance testing is suggested for verification of the geotextile supplied. Applicable test methods and frequency should be selected based on application and project size. Understanding of the statistical background to the product specification, that is typical or MARV should be kept in mind when reviewing test results against specification.

There are several laboratories in Australia that perform some or most of the geotextile standards referenced in this paper. This list may exclude other commercial, educational or private geotechnical & soil testing facilities with possible geotextile testing capabilities.

AWTA (Australian Wool Testing Authority), Victoria

CSIRO Textile and Fibre Technology, Victoria

GEOPAVE (VicRoads), Victoria

Geosynthetic Testing Services, New South Wales

Queensland Department of Main Roads, Queensland

6 REFERENCE / SOURCES

M G Sadlier Geotextile Specification – A Buyers Warning (2007)

General internet search for laboratory facilities, including www.nata.asn.au

Standards Australia: Geosynthetics – Guidelines on Durability, Technical Handbook HB 154-2002 (Note: Annex B- contains a listing of similar international test standards).