Implementing the Geosynthetics Hierarchy

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Abstract

Similar to Maslow's hierarchy of needs that motivate human behaviour, geotextiles in civil design and construction should follow a "hierarchy of needs" or requirements prior to design specifications being finalised for all forms of Civil and or Structural applications.
The levels of requirements that need to be recognised include, but are not limited to:

1. The need for confidence in repeatable performance.
   This relates to the reliability of manufacturing processes and related quality control and quality assurance methods.

2. The need for survivability during installation.
   This relates to mechanical properties that are indicative to warrant minimal-to-no damage during installation.

3. The need for the product to last the expected design-life.
   This relates to the assessment of the parameters outlining the durability of a geotextile.

4. The need for the desired technical performance.
   This relates to the mechanical and hydraulic properties, which are represented from the relevant index tests carried out on the geotextiles.

Keywords: Geotextile, Manufacture, Reliability, Installation, Durability

1 Introduction

The objective of this paper is to highlight the need for the implementation of a system of core requirements when specifying geotextiles. It is important for engineers to recognise that the incorporation of a holistic approach during the design selection process of the desired geotextile can improve the overall design which can translate into the construction phase for all civil applications.

It also aims to clearly define the proposed level of requirements in context of manufacturing, design and specifications and construction. Reliability, installation, product life and durability are fundamental components that are often overlooked in design and construction specifications. Focus is primarily placed on "technical performance" characteristics.

This paper aims to enhance the design approach by understanding the technical information of the above mentioned components that can assist in developing the level of requirements that need to be identified and analysed during the finalisation of the design specification process.

2 Hierarchy of Needs in a Geotextile

2.1 Reliability

Reliability, identified as one of the core level of requirements, can be coupled with the manufacturing process. In order to ensure that the geotextile is performing consistently well, the manufacturing process needs be understood. Further, the manufacturing process is underpinned by a stringent fully integrated quality control management system that allows the technical performance of the geotextile through testing, to be captured, measured, calculated and documented in line with the required design standards outlined.

In this case it is important to analyse the source of the material used for manufacturing and check the parameters to ensure that the end product is consistent, thus reliable. This helps in determining that the specified geotextile will perform its design function for the relevant application in a reliable manner.

Geotextiles vary in the type of polymer (raw material) used to develop the type of fibre and the fabric style. Fibre types and fabric styles have been developed for use in a number of general and specific applications. The vast majority of polymers used in geotextiles are derived from hydrocarbons. The chemical and environmental endurance required can be traced to the type of polymer used in the geotextile's manufacture. Fibres used in geotextiles are predominantly made from Polypropylene (PP), Polyethylene (PE), Polyethylene terephthalate (PET) and Polyamide (Cassidy, P.E. et al., 1992).

The commencement of the geotextile manufacturing process lies with the monitoring processes and testing of these fibres. The production of geotextiles from feedstocks which are variable in nature (such as a high level of recycled content) compared to virgin polymers or resins impacts the quality of the end product which may in turn be variable. In general, plastics cannot be easily or cheaply sorted by sight, therefore compromising the quality of recycled material sourced (Carné Sánchez and Collinson, 2011). Virgin resins are typically more rugged on the molecular level than resins that have been recycled due to their difference in molecular structure which has not undergone multiple alterations is its processing (Carné Sánchez and Collinson, 2011).

The monitoring and testing of the raw material batches needs to comply with Quality standards to ensure consistency in production.

From a technical approach, in order to satisfactorily extrapolate tests results from one specific point in time to future production batches, it is necessary that the raw materials from which the geotextiles are made, are absolutely consistent in properties (within an acceptable, predetermined specification). It is important to note that the incorporation of a recycled polymer has been recognized as a source of variability, and its use is effectively limited in other global regions or applications (Cassidy, P.E. et al., 1992). Further, no guarantee can be given that the product supplied today is made of materials with the same properties as the original installation.

Over and above the analysis of the polymers and testing of fibres, which ensures the reliability of the geotextile, further manufacturing processes needs to be discussed. These manufacturing processes flows into the other level of requirements of durability and installation which will be discussed further.

2.2 Installation

Geotextiles have been used for many years in various key applications such as separation, filtration, reinforcement and protection. In order to execute any of these functions well, it is essential that the geotextile remains intact and is not damaged or punctured due to installation stresses incurred during the construction phase.

Analyses and field tests indicate that the critical period in the life of a geotextile is during the installation and construction phases rather than during the service life. (Diederich, R. 2000). Cheah et al. notes that not only can installation damage on a geotextile affect the mechanical strength, but also the functionality such as filtration or separation which can be undermined (Cheah et al). Based on this, it can be expected that if the geotextile is able to endure the installation damage experienced during the construction phase, it will also be able to perform its intended function as per the design for the relevant application. According to Cheah et al., impact resistance and evaluation of retained strength on geotextiles; test results found that a lighter weight staple fibre non-woven geotextile outperformed the heavier continuous filament non-woven geotextile, which implies that the use of mass per unit area as a relative indicator for installation robustness should be discouraged.

In earlier times, geotextiles were frequently specified by either weight per unit area or by "brand name or equivalent". Many countries subsequently developed a more scientific approach and introduced different national specification and classification systems (Diederich, R. 2000). Based on this, it can be supported that the need for the implementation of the Geosynthetics hierarchy is necessary.

To ensure installation damage is minimised, mechanical properties of the geotextile are specified to allow the product to meet and possibly outperform the application requirements. Certain national European classification systems are now beginning to incorporate the "elongation factor" into the combination of key technical properties and express the performance requirements in terms of the energy absorbing capabilities of the geotextile. Energy absorption is defined by the area under the stress–strain curve. The energy absorption (kN/m) is the maximum energy a geotextile can absorb before failure (Diederich, R. 2000). Diederich further explains that a clear correlation between energy absorption and damage resistance has been found for all geotextiles tested, independent of their manufacturing process and physical structure. A common criteria based on the energy absorption principle allows the designer to select the appropriate product performance depending on the different applications and site conditions. The test method developed allows a rapid and precise damage evaluation of Geosynthetics and may be used as a basis to help determine performance related criteria (Diederich, R. 2000).

Energy Index (based on tensile test according to EN ISO 10319)
The use of the energy absorption potential of a geotextile is being increasingly recognised as one of the main characteristics in describing a geotextile's damage resistance. Research from several independent institutes demonstrates that there is a significantly better correlation between the resistance of a geotextile to the installation stresses and its energy absorption potential when compared to typical characteristics such as tensile strength and static puncture resistance.
For geotextiles, the energy absorption is defined as the area under the stress-strain curve for tensile strength (Figure 1) when tested according to EN ISO 10319. The Energy Index (kN/m or kJ/m2) expresses the maximum energy a geotextile can absorb at maximum strength at short term.

For practical purposes, a simplified model for the Energy Index as described in Figure 1 is used, independently of the specific shape of the stress-strain curve.

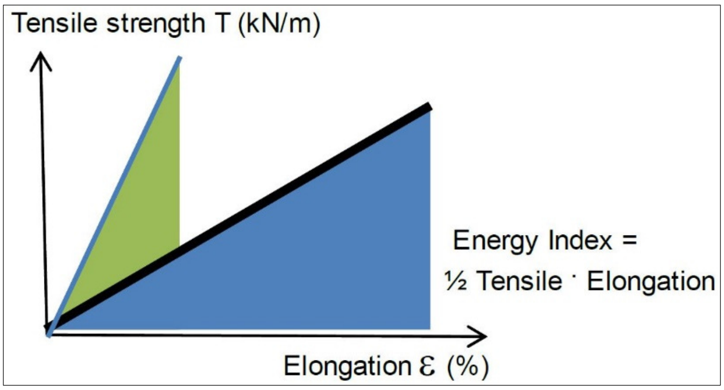

Figure 1:
A stiff geotextile needs more tensile strength than a geotextile with higher elongation to achieve the same Energy Index

According to a study conducted by Koerner & Koerner (2010), "Puncture resistance of polyester (PET) and polypropylene (PP) needle punched nonwoven geotextiles" concluded that the puncture resistance of needle-punched nonwoven geotextiles was measurably increased by changing the fibre's base resin, i.e. from polyester (PET) to polypropylene (PP) at an equivalent mass per unit area.

Three test methods were identified according to ASTM and ISO standards. Pin puncture test (ASTM D4833), pyramid puncture test (ASTM D5494) and CBR puncture test (ASTM D6241 and/or equivalent ISO 12236).

The overall results indicated that the approximate puncture resistance was greater in the polypropylene (PP) fibre based resin geotextiles over the polyester (PET) fibre based geotextiles. In particular, CBR test results measured a 25% increase of puncture resistance found in a polypropylene (PP) geotextile when tested alongside the polyester (PET) geotextile.

There are, however, many other factors between the two resin types for respective geotextiles. These factors are but not limited to needling behaviour, breaking tenacity, manufacturing methods, fibre frictional characteristics, specific gravity. The conclusion, however, stemming from the study is that needle-punched nonwoven fabrics used for protection (or cushioning) of geomembranes is better provided by geotextiles made from polypropylene (PP) fibres than those made from polyester (PET) fibres (Koerner, G.R. & Koerner, R.M. 2010).

2.3 Durability

In determining the durability of geotextiles in certain critical applications example waste containment, parameters of interest include:

2.3.1 Biological Resistance
2.3.2 Chemical Resistance
2.3.3 Moisture Resistance
2.3.4 Temperature Stability
2.3.5 Ultraviolet Resistance

2.3.1 Biological Resistance

The biological resistance of the geotextile is of importance when considering the potential degradation effect as a result of coming in contact with micro-organisms and insects in the in situ soil. Reduction factors can be used during the design process to determine the long term performance depending on the function of the geotextile and the application.

2.3.2 Chemical Resistance

The chemical resistance of the geotextile product, especially in waste containment applications, should be assessed, with respect to the performance of geotextile's raw material (polymer). All polymeric material are susceptible to degradation. Colin et al. explains that all polyamides are degraded by both hydrolysis and oxidation.

Tests have shown that polypropylene (PP) polymers used in manufacture of geotextiles have good resistance to a range of chemicals, including highly alkaline solutions, whilst polyester (PET) were affected by these highly alkaline solutions, pH greater than 10, at constant temperature, with evidence of degradation (Halse et al.). The oxidative and thermal degradation of polymers has very important implications on their suitability for critical applications (T. R. Crompton. 2010).

Further tests conducted by Mathur et al. indicated that polyester undergoes hydrolytic degradation under both acidic and alkaline conditions (pH 3-10) at higher temperatures (70-90 degrees celcius), with the degradation being more severe under alkaline conditions. The polypropylene geotextile, on the other hand, was relatively inert and showed no changes in strength under the same conditions.

The deterioration of the fibres of the geotextile due to chemical aging has a strong influence on the strength of the geotextile. The strength of the geotextile is attributed to the network of fibres within the geotextile, with each fibre having its own contribution to the overall strength and mechanical properties (Mathur et al.).

2.3.3 Moisture Resistance

Hydrolysis is a chemical process in which a molecule of water is added to a substance. Sometimes this addition causes both the substance and water molecule to split into two parts. In such reactions, one fragment of the target molecule gains a hydrogen ion. The result of this effect is a reduction in the mechanical properties of the geotextile. This reduction is however dependent on the polymer base of the geotextile and the external conditions that include pH, temperature and chemical composition of the in situ material (Jeon, H.Y. 2006).

Depending on the pH of the environment where PET are used, hydrolysis mechanisms differ substantially. In an acidic and neutral environment, water diffuses inside the polyester and causes a relatively-homogeneous degradation of the geotextile fibres. This degradation is reflected by chain scissions, which give rise to a drop in both the intrinsic viscosity and average molecular mass (Van Schoors, L.V. 2007). On the other hand, degradation in a highly alkaline environment (pH >9) is primarily localized at the surface. Given the sizeable decline in mechanical properties observed at high pH levels and elevated temperatures, a number of researchers have suggested avoiding use of these materials at pH exceeding 9. When seeking to extend material life cycles, the use of polyesters to reinforce lime-treated soils is not necessarily an appropriate course of action. Moreover, under service conditions, these polyester geotextiles are subjected to mechanical stresses capable of exacerbating degradation by means of alkaline hydrolysis, hence reducing their durability (Van Schoors, L.V. 2007).

2.3.4 Temperature Stability

The mechanical properties of the geotextile fibres deteriorate as temperatures increases. At high temperatures, it is important to note that the mechanical properties of the fibres deteriorate as temperatures increases, but polypropylene performs better than polyethylene in this respect. The softening point of polypropylene fibres is approximately 150°C, and the fibres melt at 165°C. (Cook, 1984). These factors are important to consider in a waste containment application, due to elevated temperatures.

2.3.5 UV Resistance

Polypropylene based geotextiles degrades during extended exposure to sunlight. Nonwoven polypropylene geotextiles are produced with carbon black and other UV inhibitors. These additives allow nonwoven polypropylene geotextiles to be exposed for up to 14 days between laydown and cover. (Technical Note, 1996).

2.4 Technical Performance

When specifying a geotextile for a given Civil design application or for Construction, it is extremely important that the geotextile's expected functions are known in advance. These key functions include separation, filtration, reinforcement and protection. Based on this, it is possible to specify exactly the required characteristics of the geotextile to execute these functions well, thus ensuring a holistic approach to an enhanced and correct design. The following steps, forming the Geosynthetics hierarchy and the understanding the core level of requirements, form the benchmark for this decision:

- Select the appropriate raw material and material properties.
- Select the right stabilisation of the raw material to ensure high durability.
- Select the right fibre length and thickness.
- Select the appropriate design of the needling process/ manufacturing method.
- Select the right level of thermal bonding to ensure the required strength, elongation and abrasion resistance.
- Review of the data sheet and check compliance to the relevant required standards with regards to the mechanical and hydraulic properties.

With all the above the required final mechanical and hydraulic properties of the geotextile can be achieved for intended use.

2.5 Conclusion

Based on Maslow's hierarchy of needs relating to human behaviour, the selection of geotextiles should not primarily be based on its index properties, but on factors that relate to its manufacture quality, installation procedure, the desired design life of the structure, and its function in the intended application. This selection process is intended to create a holistic approach to enhance design practice.
Ultimately, the recommended product would be one that:
a) Is made from raw materials having 100% traceability and identical in nature, and therefore guaranteed consistency in production processes. In order to measure this, one should have access to the batch results of the raw materials, quality compliance certificates as well as batch test results of the end product to assure traceability and transparency between manufacturing processes and published data sheet values.
b) Complies with global standards and recommendations, preferable CE marking which denotes European conformity.
c) Is specified in terms of design parameters/ level of core requirements identified and discussed to execute the intended design application.
d) Continues to deliver the desired technical performance required, having been installed under various conditions and site conditions.

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