

THE USE OF GEOSYNTHETICS IN PAVEMENTS: NEW TECHNOLOGY FOR SUSTAINABLE ENVIRONMENT

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Geosynthetics have grown in the civil industry in the past twenty years becoming key materials in the design of new roads and in maintenance programme. Geosynthetics are now widely used for strengthening of in situ soil, mechanical improvement of pavement layers from the sub-base up to the asphalt wearing course using different type of geosynthetics, from geotextile to geogrids and geocomposite. Management of stormwater can be achieved using geocomposite for drainage instead of traditional gravel drainage.

The paper will discuss the geosynthetic functions in pavements and their use in a pavement structure, highlighting advantages and disadvantages gained from literature and experience.

BACKGROUND

Since the introduction of geosynthetics in the early 60's in America to create a working platform for operating machineries and foundation strengthening for haul roads; the development of highly technical engineering materials combined with the research contributed to bring geosynthetics in a key-role position in projects, where the design is based on the benefit gained by the geosynthetics towards reduction of layer thickness, increment of traffic load or the use of lower quality materials.

Geosynthetics cover multiple functions (according to SANS ISO 10318-2013):

- Drainage
- Filtration
- Separation
- Protection
- Barrier
- Reinforcement
- Surface erosion control

Designers usually prefer using a function classification rather than the product classification because the geosynthetics industry groups more than 100 different products, which differ in raw materials, composition, assembly, varying the engineering properties such as mechanical, chemical and hydraulic behaviour, which is the main concern for designers.

In a broad classification, still in accordance to the SANS ISO 10318:2013, geosynthetics are classifiable in the following groups:

- Geotextiles
- Geogrids
- Geomembranes
- Geonet
- Geomat
- Geocell
- Geospacer
- Geosynthetic Barrier
- Geocomposite

Some geosynthetics are able to cover one or multiple functions while others only one. Combining the aforementioned lists together a broad overview of geosynthetics versus function is represented in Table 1

	Drainage	Filtration	Separation	Protection	Barrier	Reinforcement	Surface erosion control
Geotextiles		√	√	√		√	
Geogrids						√	
Geomembranes					√		
Geonet	√						
Geomat	√						√
Geocell						√	√
Geospacer	√						
Geosynthetic Barrier				√	√		
Geocomposite	√	√	√	√	√	√	√

Table 1: Geosynthetics type and functions

INTRODUCTION TO GEOSYNTHETICS IN PAVEMENTS

In pavements, 6 functions can apply: filtration, drainage, separation, barrier, reinforcement and surface erosion control as shown in Figure 1 below.

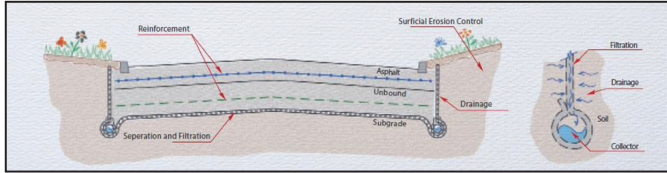


Figure 1: Geosynthetics function in a pavement

The following paragraphs will discuss each function in the pavement environment, highlighting the benefit compared to traditional solutions in order to create a general guideline on how to use geosynthetics in pavements.

Filtration function

Geotextiles are often used as a filter to restrict movement of soil particles as water flows into the drain structure. Mainly nonwoven geotextiles are used due to the high permeability (over 100 l/m²s) and high survivability in maintaining an opening size under loading which controls the retention criteria (capacity to retain the soil particles). In South Africa, geotextile specifications are still based on the unit weight while a more detailed specification should be used.

Nonwoven geotextiles are made from staple fibres or continuous filament of polyester (PET) and polypropylene (PP) bonded together by a process of needle punching and in some instance, followed by thermal bonding. The main issue of just specifying the unit weight of the geotextiles is that the unit weight is not a characteristic directly related to the hydraulic or mechanical properties of the geotextile which are key parameters for a filtration design.

In filtration function the principal properties needed for a geotextiles are:

- Retention criteria – Apparent Opening Size
- Hydraulic criteria – Permeability
- Chemical criteria – Raw material
- Installation criteria – CBR, Dynamic puncture resistance
- Long term flow – soil / geotextile interaction

The unit weight is not mentioned in the above requirements for filtration function. A guideline to correctly specify the geotextile should be to follow the retention and hydraulic criteria (AOS and permeability) followed by the chemical criteria based upon the chemical properties of the fluid (PET is sceptical to high values of PH) and lastly the installation criteria looking at the mechanical properties.

The long term flow governs the clogging of the geotextile (the permeability of the geotextile reduces). This is a particular argument because it requires the assessment of the behaviour of the filter system soil-geotextiles altogether. There are available laboratory tests to perform such analysis but they are quite expensive and not easily available in South Africa. A more experienced approach based on assuring that clay or silt particles is not in direct contact with the geotextile is a good practice to avoid clogging phenomena in most cases. If the design is critical (filter for a dam wall or a landfill) further investigation is strongly recommended.

Furthermore, due to the possibility of clogging by nonwoven geotextile when used in a clay environment, woven geotextiles are used sometimes due to the bigger opening size (200 µm and more) and the small thickness which avoid the soil particle to get trapped in the geotextile structure. However, woven geotextiles are characterised by a low permeability in order of 10 times less than a nonwoven geotextile, nevertheless

woven geotextile varies the hydraulic properties with the tension state applied, especially in pore size as shown in Figure 2.

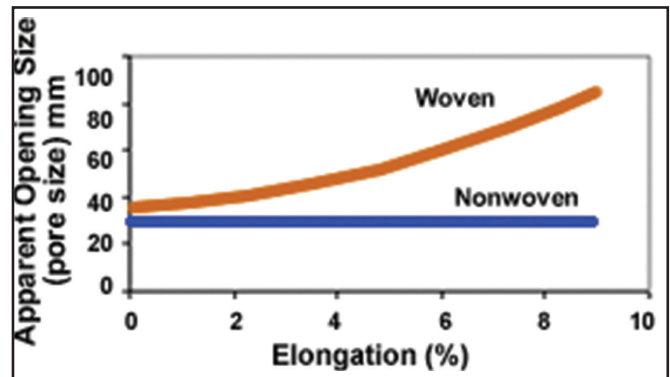


Figure 2: Change in pore size with increase in load / strain

Nonwoven geotextiles are the preferred geosynthetics to perform a filtration function. Specifications should be more engineering based rather the cost based (the weight of a nonwoven geotextile is directly related to its cost). Woven geotextile might be used for filtration function but care to the hydraulic properties is paramount.

Drainage function

As per SANS ISO 10318:2013 drainage function is defined as “collecting and transporting of precipitation, ground water and/or other fluids in the plane of a geotextile or a geotextile-related product”. Management of water is paramount in a pavement structure because if not accurately managed, it can compromise the lifetime of the pavement affecting the pavement’s settlement as well as the quality of the pavement layer. Figure 3 represents the reduction in resilient modulus of a granular material in the 3rd phase when the pavement is considered to reach the end of its design life (asphalt cracking might allow water to seep into the pavement or the subsurface drains are blocked, not collecting the water from the surroundings).

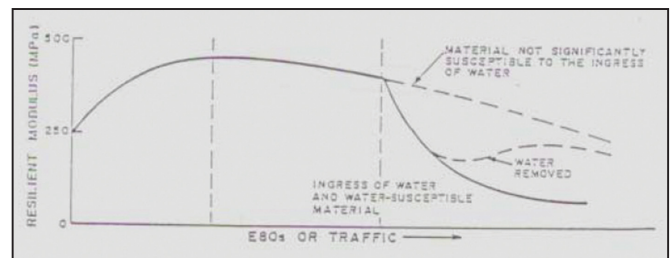


Figure 3: TRH 12: Influence of water in a granular material

Geosynthetics, especially geocomposite for drainage replace traditional drainage structure such as open graded sub-base or sub-surface interception drain. Laboratory tests undertaken in Brazil have shown that geocomposite for drainage compared to traditional gravel drainage are more effective because they are manufactured in a controlled environment and they undergo laboratory tests to assure the quality of the performance while traditional gravel drains are subjected to the quality of the gravel and the quality control on site to assure proper installation.



Figure 4: Geocomposite for drainage (Left) – Drainage test (Right)

	Traditional gravel drain	Geocomposite for drainage
Q _{in} (ℓ/s)	2.20 x 10 ⁻¹	2.20 x 10 ⁻¹
Q _{out} (ℓ/s)	1.18 x 10 ⁻³	1.10 x 10 ⁻²

Table 2: Control of water drained after 30 minutes

After 30 minutes the geocomposite for drainage drained 10 times more water than the traditional drain. Furthermore the installation cost and time of using geosynthetics are about 48% cheaper than traditional drainage as shown in Table 3. Further advantages are the sourcing of material from a sole supplier instead of two (geotextile and crushed rock supplier are usually different) reducing the standing time of the contractor due to missing material on site.

Sub soil drainage - Traditional	BOQ/l.m	Unit Cost Rand	Total Cost Rand
Class I – Crushed rock stone aggregate with little or no fines (19mm)	0.33 m ³	240/m ³	79.20/mℓ
GTX-N 300g/m ²	2.13 m ²	20/m ²	42.60/mℓ
Perforated pipe Ø 110 mm	1.00 m	30/mℓ	30.00/mℓ
Labour	4 h	42.80/h	171.20/mℓ
Cost per linear metre			R323.00/mℓ
Sub soil drainage - GCO	BOQ/l.m	Unit Cost Rand	Total Cost Rand
Geocomposite for drainage	1 m ²	70/m ²	70 m ²
Class I – Crushed rock stone aggregate with little or no fines (9-38mm)	n.a.	n.a.	n.a.
GTX-N 300g/m ²	n.a.	n.a.	n.a.
Perforated pipe Ø 110 mm	1.00 m	30/mℓ	30/mℓ
Labour	2 h	42.80/h	11.8/mℓ
Cost per linear metre			R 155.00/mℓ

Table 3: Bill of quantity for 1m deep and 1m length sub-surface drainage



Figure 5: Geocomposite for drainage as anti-capillary for a railway embankment

Separation function

Separation is often used to avoid mixing of dissimilar materials such as good imported material with insitu material (usually very weak). Mostly geotextiles are suited for this function because they support the imported material to punch into the soft material (localised bearing failure). Furthermore, the separation function works closely with the filtration function because the water seeping into the road due to the dynamic loading is filtered by the geotextile avoiding contamination of the drainage base which reduces the mechanical properties of the base (pumping).

Traditionally, excavation is often required to import rock pioneer layer to strengthen the subgrade, however this procedure is time consuming and expensive, nevertheless excavation disturb the weak soil, breaking the chemical bonding (apparent cohesion) of mainly clays, reducing the mechanical properties even further. The increment of bearing capacity generated by the geotextiles reduces the quantity of imported material (both rock and granular) because the CBR required is achieved with fewer thicknesses.

Nonwoven geotextiles are often used in temporary roads such as access road to rural roads with a low volume of traffic; woven geotextiles, characterised by the high strength and installation survivability are used for industrial roads, haul roads and foundations.

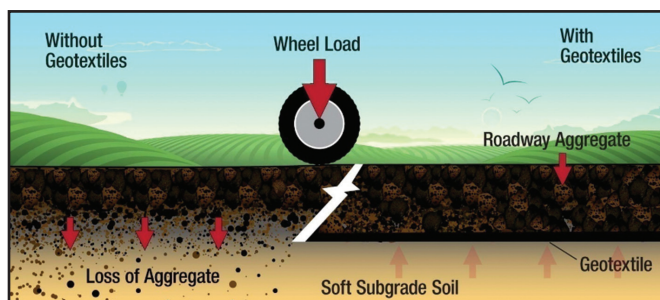


Figure 6: Separation function

Reinforcement function

Reinforcement function is nowadays the most important function in pavements.

Geosynthetics, mostly geogrids and some geotextiles are able to perform such function which requires high mechanical performance of the geosynthetics during the time.

Three mechanisms occur when a geosynthetic is placed in a pavement structure to perform a reinforcement function:

- Lateral restrain – a classical pavement failure is the excessive rutting cause by the lateral shoving of the aggregate over soft soil which provide very little lateral restrain. Only geogrids can perform this function because their open structure, allow the granular material to interlock, avoiding further lateral movement.
- Bearing Capacity increase – Geosynthetics are strong in tension, therefore considering a classical failure in bearing capacity, when the

failure plane intercepts the geosynthetics, the displacement activates the reinforcement, increasing the allowable shear stress of the soil increasing the bearing capacity support by modified the slip failure plane

- Membrane Support – Geosynthetics spread the load reducing the pressure on the insitu subgrade. In order to develop this benefit there shall be enough deformation in the geosynthetics to carry the with-standing load as well as a soft subgrade to allow the geo-synthetics to deform. Studies have been proven that a rutting of 100mm and a CBR<3 are condition for developing membrane support conditions.

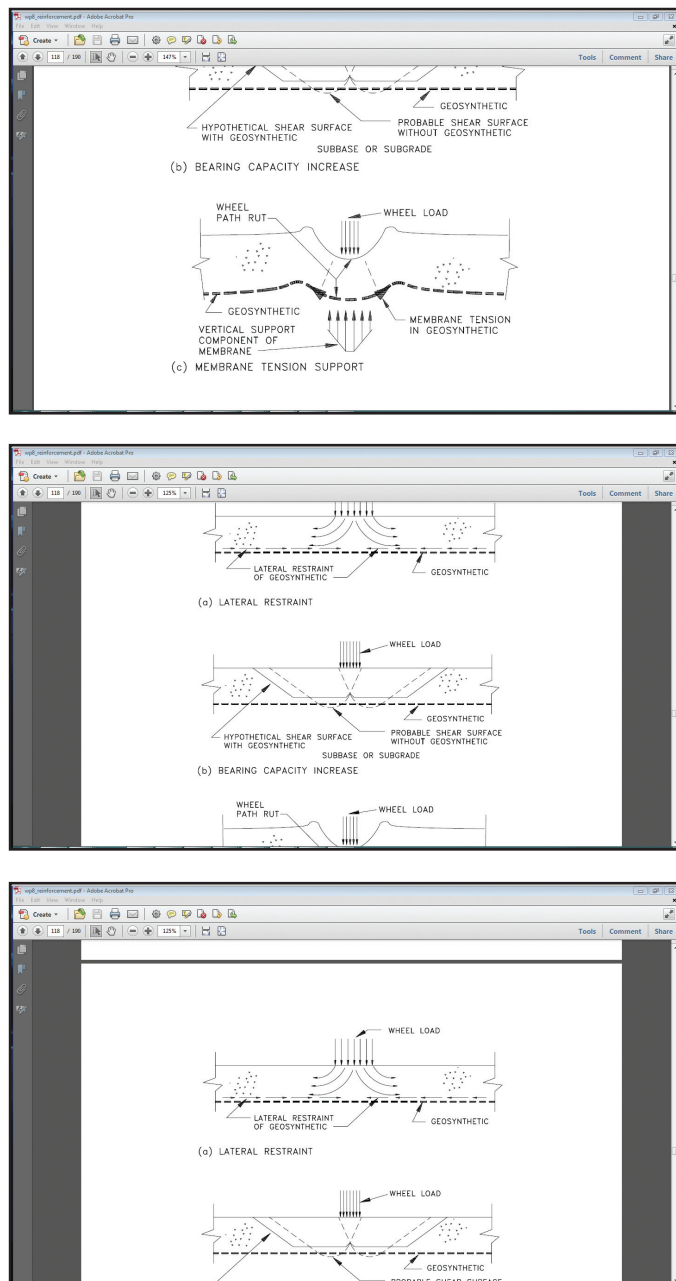


Figure 7: Reinforcement function (Lateral restraint – Bearing capacity – membrane tension support)

Reinforcement in wearing course

The primary functions taken into account for the design and construction of the wearing course are:

- protection of the existing surface against water intrusion,
- reduction of roughness on the riding surface,

- restoration of skid resistance,
- increase of the structural capacity, and
- improvement of the overall ride quality.

The wearing course is designed to crack from the bottom to top (crack propagation bottom –top). Once cracks are developed in the wearing course moisture enters in the pavement degrading the pavements. For many years and still today, nonwoven geotextiles have been used mainly as a moisture barrier with very small reinforcement contribution due to the very low tensile strength. Nowadays, geogrids reinforced with high elastic moduli such as glass or steel have been successfully used. Geocomposites as well geotextile and geogrids) are used in order to still obtain the moisture barrier as well as the reinforcement.

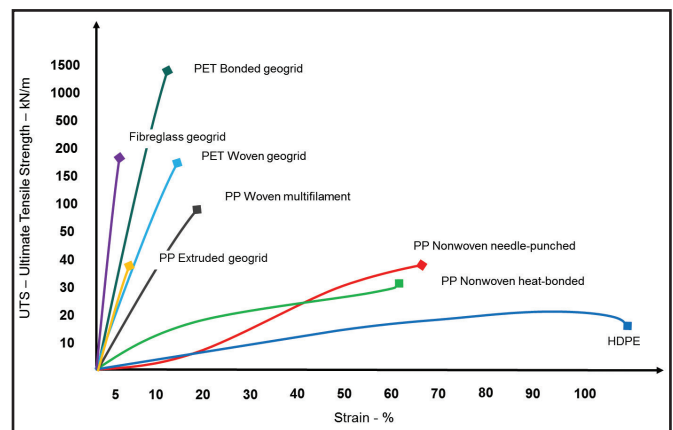


Figure 8: Geosynthetics typical stress-strain curve

Barrier and erosion control functions

Barrier and erosion control functions find place in a pavement in case specific applications. Barrier function is seen as the extreme of filtration because a geosynthetic barrier does not allow any gas or liquid to flow through. Geosynthetic barrier are usually used when no water is allowed in the pavement structure; however a barrier system is always combined with a drainage function in order to manage any excess of pore water pressure developed by restraining the water to flow under pressure. Geosynthetics barrier are often used in overlays in order to control the moisture entering in the pavement due to cracking phenomena. The erosion control function is often used to prevent erosion of slopes, by run-off water or to manage side water drains.

BENEFIT OF USING GEOSYNTHETICS IN PAVEMENTS

The benefit of using geosynthetics in a pavement structure is measured by:

- TBR – Traffic Benefit Ratio – ratio of the number of load cycles on a reinforced section to reach a defined failure state to the number of load cycles on an unreinforced section, with the same geometry and material constituents, to reach the same defined failure state
 - BCR – Base course reduction: The percent reduction in the reinforced base, or subbase, thickness from the unreinforced thickness, with the same material constituents, to reach the same defined failure state
- Furthermore (directly from GMA – White paper II):

- Reducing the intensity of stress on the subgrade and preventing the base aggregate from penetrating into the subgrade (function: separation).
- Preventing subgrade fines from pumping or otherwise migrating up into the base (function: separation and filtration).
- Preventing contamination of the base materials which may allow more open-graded, free draining aggregates to be considered in the design (function: filtration).

- Reducing the depth of excavation required for the removal of unsuitable subgrade materials (function: separation and reinforcement).
- Reducing the thickness of aggregate required to stabilise the subgrade (function: separation and reinforcement).
- Reducing disturbance of the subgrade during construction (function: separation and reinforcement).
- Allowing an increase in subgrade strength over time (function: filtration). Reducing the differential settlement of the roadway, which helps maintain pavement integrity and uniformity (function: reinforcement). Geosynthetics will also aid in reducing differential settlement in transition areas from cut to fill. [NOTE: Total and consolidation settlements are not reduced by the use of geosynthetic reinforcement.]
- Reducing maintenance and extending the life of the pavement (functions: all).

GENERAL GUIDELINE ON THE USE OF GEOSYNTHETICS IN PAVEMENTS

The following paragraphs aimed to propose a general guideline on the use of geosynthetics in pavements gained from literature, experience modified to suit South African and generally African conditions through a flexible pavement structure.

Geosynthetics in the foundation

Filtration, separation, drainage and reinforcement functions can be used to assure stability of the embankment foundations. Weak soil is characterised by a low shear stress, when the embankment is placed over, a failure in bearing capacity (undrain) might occur, as well as lateral spread of the embankment over the top soil.

Mainly drainage and reinforcement are key function for foundation stabilisation: the use of vertical drain (known in the industry as prefabricated vertical drains - PVD's) reduce consolidation time facilitating the drainage of water from the insitu soil. Reinforcement using high strength geogrids allow the construction of embankments in a shorter time taking care of short time failures (when the soil is saturated and acts in undrain shear stress). If settlements control is required a combination of piling and geogrids allow the reduction of the number of piles, having the reinforcement spanning across the pile holding the soil on top. The same concept can be applied for soil where subsidence might occur.



Figure 9: Basal reinforcement with geogrid (left) – Consolidation using PVD's (right)

Geosynthetics in the subgrade

Subgrade characterized by a CBR less than 15 (G9 – G10 as per TRH 14) requires import of selected subgrade such as G7 or G9; if the CBR is less than 3, then chemical stabilisation or import of rock pioneer layer is common practice. Depending upon the CBR values the following functions can be considered:

Undrained Shear Strength (kPa)	Subgrade CBR	Functions
60 – 90	2 - 3	Filtration and possibly separation
30 – 60	1 - 2	Filtration, separation and possibly reinforcement
< 30	<1	All functions, including reinforcement

Table 4: Function of geosynthetics varying the subgrade CBR

If groundwater management is necessary a geocomposite for drainage can be placed above the separation geotextile or actually work as a separation function itself (if it can cope with the mechanical properties required).



Figure 10: Woven geotextile place as a separator and reinforcement between subgrade and subbase

Geosynthetics in the subbase and base

Reinforcement function (aka ground stabilisation) can achieve either a reduction in the subbase and base thickness (BCR) or a increment of volume of traffic (TBR). Often BCR is preferred to TBR because usually the cost of the pavement structure is above budget or the volume of available material is not sufficient to withstand the demand.

Depending on the type of the pavement, temporary or permanent, different designs methods are available. Design methods are based on empirical tests (sometimes backed up by mechanistic models) in order to evaluate what is the benefit of geosynthetics on a pavement structure. The inputs are the traffic volume, the category of the road and the mechanical properties of the layer works. The output is the thickness of the pavement structure with and without geosynthetics. Due to the different background of those methods, a checking procedure shall be in place to assure that the traditional design without geosynthetics matches in thickness any other design method (TRH 14, SAMPD, BISAR, etc...).

For temporary roads, often geotextiles both nonwoven and woven are used while in permanent roads, geogrids (mainly extruded to enhance the lateral restraint) are preferred.



Figure 11: Lateral confinement (left) – Extruded geogrids installed between subbase and base (Right)

Usually the BCR varies between 20% and 40% as shown in figure 11 where the design was based on a subgrade with a CBR of 0.5% with and 2 million ESAL. The reduction was respectively 30% for the base course and 39% for the subbase inserting n.2 extruded geogrids.

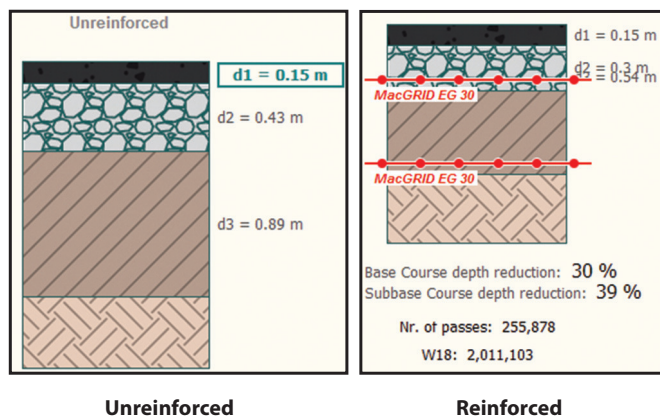


Figure 12: Comparison of unreinforced and reinforced pavements using geogrids

Geosynthetics in the wearing course and overlay

Wearing courses are the most expensive materials in a pavement structures, but nevertheless are one of the most important. The use of geosynthetics has recorded good successes as well as terrible failures. Most failures occurred in shear at the bottom of the reinforcement level because inappropriate installation guideline were used. The use of geosynthetics in the wearing course or even in the overlay requires a perfect

bonding between bottom layer – reinforcement and reinforcement – top layer. Geosynthetics are weak interfaces where shear can occur; if prime or tack coat is not installed correctly the pavement will fail. However the benefit in thickness reduction from 20 to 35% was recorded using the right geosynthetics and installation methodology. Geogrids made of glass or steel are preferred having a very high elastic moduli, developing tensile strength at very low deformations.

In order to control the bonding of the reinforcement on the bottom and top layer, geocomposite geogrids have been developed where attached geotextiles assure the bonding of the geogrid not only on the rib but on the whole surface. Further steel geogrids made of double twisted mesh outperform due to the tri-dimensional structure which interlocks the top layer allowing a full bonding with the bottom layer. However a minimum thickness of 50mm is required while for geogrids made of glass, 35mm is acceptable.



Figure 13: Geogrid in steel (left) and a geocomposite (right)

Geosynthetics used in wearing course as well as in overlay can create a significant contribution as shown in figure 13 for both steel and fibre-glass reinforcement in an overlay.

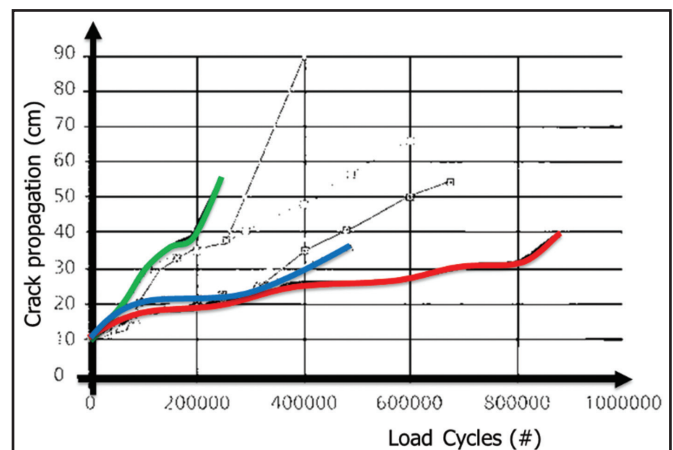


Figure 14: Crack propagation delay in an overlay using steel and fibre-glass reinforcement

SPECIFICATIONS OF GEOSYNTHETICS

An important aspects of geosynthetics is the specification in tender documents and drawings. A good design can be undermined by incorrect products and installation specifications. South African designers have understood the outdated specifications available (ie. COLTO, SANS or TRH), however the knowledge on geosynthetics sometimes is scattered, resulting in incorrect specifications up to the stage that also the names are incorrect, generating confusion in the procurement stage or even in the construction stage. Literature is available through books, CPD lectures and courses run by manufacturer or independent organisations such as the Group of Interest of Geosynthetics in South Africa (GIGSA); who are striving to increase the knowledge of geosynthetics in all the civil engineering fields as well as in pavements.

Common errors are:

- Nonwoven geotextiles for filtration function using the mass (actually still called filter fabric which was withdrawn in 1977 to avoid misunderstanding with the textile industry)
- Geogrids for ground stabilisation where installation damage and chemical reduction factors are not present
- Geosynthetics for soil reinforcement specified only using the ultimate tensile strength instead of the design strength which account for creep, installation damage and chemical aggression.
- Geocomposite for drainage where only the core specification were mentioned, missing influence of the geotextile intruding in the core reducing the drainage capacity of the core (up to 10 times).

CONCLUSION

In the past 20 years geosynthetics have succeed in pavements, from rural roads to highways and airports and container yards reducing layer thicknesses, managing settlements and soils which was not developed due to the high costing of reclamations.

Geosynthetics, such as geotextiles, geogrids and geocomposite for drainage are used for filtration, separation, reinforcement and drainage using local labour (intensive labour technology) in South Africa and abroad with success from subgrade reinforcement, sub base and base strengthening to asphalt and overlay reinforcement.

Successful projects are attainable only if the design is based on correct assumption and used within the limits of its development (being most of them empirical); products shall comply with primary specifications managed by appropriate quality control procedures and supported by correct specifications.

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