Weathering: Degradation of Geomembranes

MAY 2012

WHITEPAPER

It can be difficult to identify which geomembrane product will be best suited to perform long-term in a targeted environment. By addressing the exposure to weathering and the effects on the geomembrane, there is a greater chance for improved long-term performance. The type of polymer used in the geomembrane determines how it will perform over time when exposed to the environment.

This article includes:

- Effects of weathering on:
  - Geomembrane vulnerability
  - Linear thermal expansion
- Most commonly used geomembranes
  - Polyethylene
  - Thermoplastic polyolefin
  - Ethylene Interpolymer Alloy
  - Polyvinyl chloride
- Polymer failure
  - Degradation process of the polymer
  - Stabilization of the polymer
- Artificial simulation of weathering
- Points to consider in exposed applications
- Conclusion

Effects of Weathering

Geomembrane Vulnerability

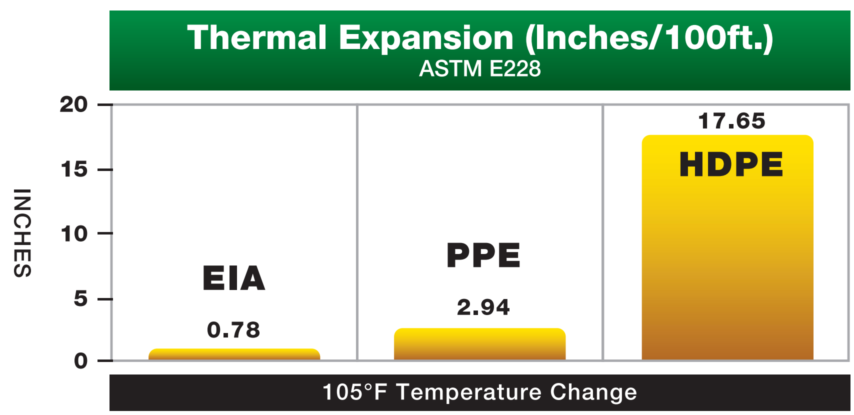
Solar radiation (light energy), temperature and water, and other environmental contaminates are all factors that may affect exposed geomembranes. The shorter wavelengths found in the ultraviolet (UV) region of sunlight have proportionally higher photon energy. Polymers are susceptible to degradation from exposure to radiant energy in this region. When the absorption of radiant energy is greater than the molecular energy holding the polymeric matrix together, a photochemical reaction occurs. This reaction results in scission at the molecular level of the polymeric composite. The first indication of potential degradation is the reduction in molecular weight of the polymer.

XR GEOMEMBRANES
By Seaman Corporation

The result is a steady decline in the geomembrane properties, such as the reduction in physical and impact strength, elongation, ductility, brittleness, discoloration, cracking, crazing and chalking. The performance of the geomembrane is directly related to the performance of its properties as a whole. A large reduction in physical properties, such as tensile, tear and puncture indicate the performance has been jeopardized. All aspects of the application must be taken into consideration because once degradation begins it will continue until the useful life of the polymeric system is depleted.

Linear Thermal Expansion

The coefficient of linear thermal expansion measures a material by how much it expands for each degree of temperature increase. This is important in design calculations as the material will expand or contract, depending on the temperature; intense temperature swings may lead to mechanical stress failures. Thermal expansion must be taken into consideration as the higher the linear coefficient of thermal expansion of the polymer, the greater the growth and contraction. This will result in potential thinning of the geomembrane.



In applications where the expansion and contraction of the geomembrane is critical, the combination of the lower coefficient of thermal expansion polymer with polyester-reinforced scrim would provide for a highly stable solution. Polyester is a dimensionally stable polymer when exposed to heat and moisture. These features can be found in the ethylene interpolymer alloy (EIA) geomembranes.

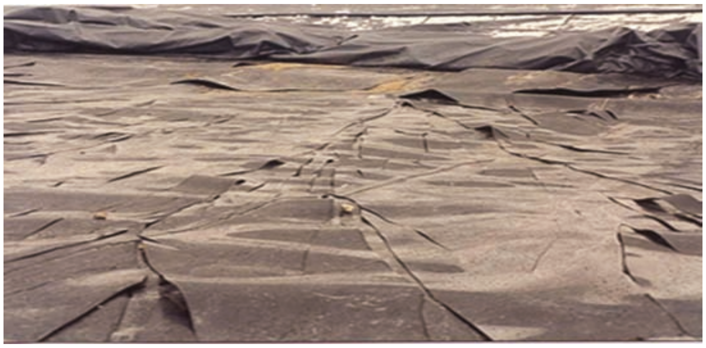
Most Commonly Used Geomembranes

Polyethylene (PE)

PE is a thermoplastic created by the polymerization of ethylene. The classification of high density polyethylene (HDPE), linear low density polyethylene (LLDPE), and LDPE are based on the branching, molecular weight, crystallinity and density of the polymer.

In HDPE, the high crystallinity contributes to its susceptibility to stress cracking. Stress cracking is the result of the deformation of the geomembrane under low stress that causes the platelets of the PE to disentangle. In general, the installation of the geomembrane may induce stress cracking. This may include practices such as overheating during welding of the PE, concentrated stress and differential in settlement, and pinched wrinkles or waves in the material (I. Peggs).

HDPE geomembrane failure in Asia, 2010



http://geosynthetica.net/news/article/2010/HDPE_FailuresInAsia_021610.aspx

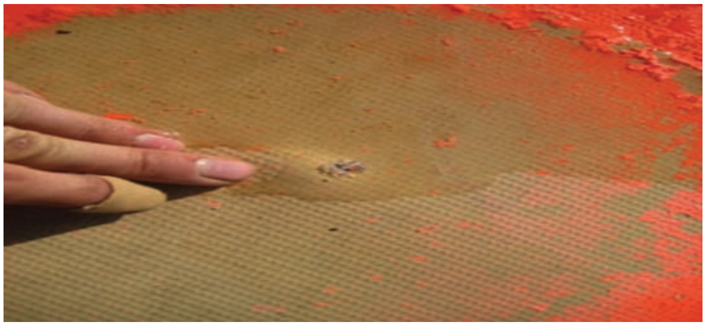
Suggestions from Asia are that the causes of these failures are local manufacturers using recycled HDPE; insufficient carbon black in the formulations; insufficient OIT (under 10 minutes); or poor resins.

Environmental stress cracking (ESC) occurs in the presence of internal/external stresses. Macroscopic cracks form, creating a route for absorption of stress cracking agents and moisture. The absorption of the liquid through the crack plasticizes the polymeric matrix and causes the crack to expand. It is important to note that ESCR is extremely sensitive to temperature. Crack-growth data generated on PE suggests that for every 7°C increase in temperature, the crack-growth rate is doubled (Lustiger). PE may have a high chemical resistance to a specific liquid environment but under polyaxial stress (including stored stresses from extruding or molding) the material will suffer from ESC.

Thermoplastic Polyolefin (TPO)

TPO is the composite of polypropylene (PP) and ethylene-propylene (EP) rubber. Molecularly, the EP component provides flexibility to the membrane. In the geomembrane market TPO is typically referred to as PP. Ultraviolet (UV) light, heat and environmental exposure all play a role in the degradation of this polymer system. PP is very susceptible to thermal degradation. It relies on chemical additives to stabilize the polymers at ambient temperatures and inhibit molecular fracture to deter degradation of the membrane. Degradation of PP in the field can result in degradation and scrim exposure. This leads to failure of the geomembrane as seen in the illustration below:

Exposed TPO Reinforcement Due to Polymer Degradation



http://geosyntheticsmagazine.com/articles/0611_f5_geomembrane_performance.html

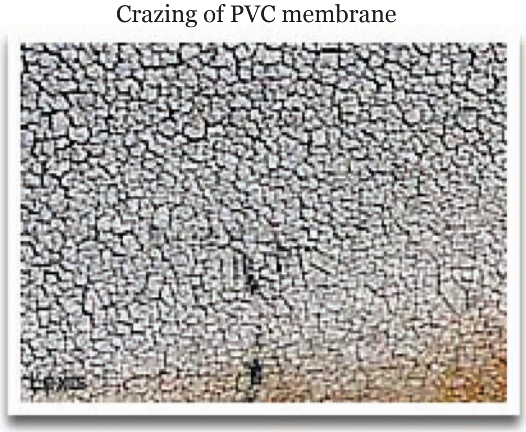
Ethylene Interpolymer Alloy (EIA)

EIA geomembranes are based on an ethylene terpolymer, which exhibits excellent thermal and chemical stability. Trade-named XR-5®, the polymer has shown drastic improvement in outdoor life compared to crystalline products such as HDPE or to liquid plasticized products such as PVC. Additionally, the compound has extremely low thermal expansion-contraction properties. The polymer structure allows the use of a heavy reinforcing fabric while maintaining a light overall membrane package. The result is that reinforcement provides the strength and does not rely on the polymer for strength performance. The picture below illustrates the durability of the EIA membrane in an exposed application for over 28 years.

Polyvinyl Chloride (PVC)

Degradation of PVC membranes typically occurs as a result of plasticizer migration and high thermal exposure. Plasticizers are used to make the PVC flexible. At elevated service temperatures, the thermal exposure will break down the polymeric coating and release hydrogen chloride (HCL) that will assist in the degradation of the PVC system. Crazing on the surface of the PVC membrane, typically a result of plasticizer migration, can be seen below:

Crazing of PVC membrane

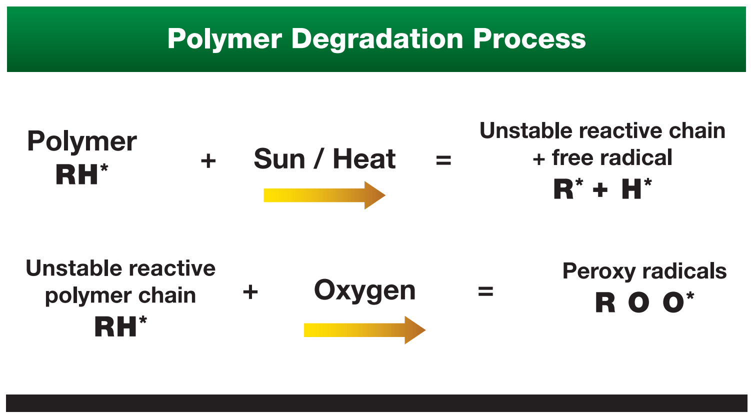


http://www.lexiscoatings.com/single-ply/

Polymer Failure

Degradation Process of the Polymer

Photo-oxidation and thermal degradation are significant factors when addressing the weathering of polymers. Photo-oxidation is “degradation on the polymer surface in the presence of oxygen”. Thermal degradation is a result of “molecular deterioration as a result of overheating”. The destructive effects of light are usually accelerated at elevated temperatures as a result of the increased rate of secondary molecular reactions. The degradation process, illustrated below, occurs as a result of heat, light and/or oxygen absorbed by the polymer matrix.



The radicals join with polymers on a molecular level, split, continue to generate free radicals, and the reaction of polymer degradation continues. The reaction of different free radicals with each other can occur; polymeric chains react with each other, referred to as cross-linking, resulting in embrittlement of the polymer.

Stabilization of Polymer

To ensure long-term performance, the polymer coating must be properly protected from exposure. The polymer is protected by blocking or filtering out harmful wavelengths so that they cannot generate free radicals, and/or by interfering with the reaction of free radicals, if they have already been generated.

Pigments such as carbon black, TiO_2, or others, can be incorporated into the polymer to block, reflect or absorb UV radiation. UV absorbers such as benzophenones, benzotriazoles, or triazines, preferentially absorb UV radiation so that it does not react with the polymer to generate free radicals.

Light stabilizers, such as hindered amines, phenols and to some extent, carbon black, interfere with the reactions of free radicals that have been generated by UV or high temperature exposure, stopping reactions that will cause further damage to the polymer. UV absorbers are often used in combination with light stabilizers.

In polymers that are susceptible to oxidation at high temperatures, antioxidants are added to prevent polymer degradation, a common problem during the molding and extruding operation. Over time, some additives are at risk of being consumed during the exposure of the geomembrane and are vulnerable to environmental degradation.

Artificial Simulation of Weathering

The objective of artificial weathering is to give a correlation of long-term performance of the geomembrane to natural exposures on the Earth's surface. Typical test procedures expose the geomembrane to a specific amount of energy at various wavelengths, over a specific length of time. Environmental conditions such as freezing and thawing, contaminates, and acid rain are not taken into consideration in a controlled laboratory environment.

Xenon Arc
By Atlas Electric Devices

There are two common artificial light sources that are used to evaluate degradation. The Xenon arc tester with daylight filters, in accordance with ASTM G155 Standard Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials, duplicates the entire spectrum of sunlight (solar radiation). The irradiance and temperature is controlled; humidity and water spray are available.

Fluorescent UV-A340
By Q-Panel

Fluorescent UV-A340 bulbs have excellent correlation in the UV wavelength range of 295nm – 370nm and offer humidity as a moisture source, in addition to temperature control. These light source devices are in compliance with ASTM G154 Standard Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials.

In PP and PE polymer systems where oxidation stability is critical to the long-term performance of the geomembrane, oxidation induction time (OIT) is evaluated. Testing is performed to ASTM D5885 Standard Test Method for Oxidative Induction Time of Polyolefin Geosynthetics by High-Pressure Differential Scanning Calorimetry. This test subjects the material to temperature under pressure for a specified time in the presence of oxygen. It is not used to determine life expectancy of the material but to give an indication of polymer stability by the addition of additives at the time of manufacture.

Differential Scanning Calorimeter (DSC)
By California Polytechnic State University

Thermal degradation can be evaluated in a laboratory by subjecting the geomembrane material to high temperature over an extended period of time; this is typically referenced to as "oven aging". This test strictly evaluates the degradation as a result of heat and does not take other degradation mechanisms into account. Field correlation testing would need to be performed to determine equivalency to outdoor exposure. In addition, deadload testing (static load) on the seams at elevated temperatures, is performed in a standard laboratory air-circulating oven. This test is a good indication of seam integrity in an exposed environment, under load at elevated temperatures, and can be found in ASTM D751 Standard Test Methods for Coated Fabrics.

Points to Consider in Exposed Applications

At the start of the selection process, one must determine the strength, stability, and chemical resistance required for the specific project. In addition, the following should be considered to provide for a long-term high-performance geomembrane in an exposed environment:

- Application
  - Sloped or flat – different angles of installation can increase UV exposure
    - Select geomembrane with superior UV resistance
    - Drainage and anchoring issues associated with high thermal expansion/contraction
    - Dead load critical on factory and field seams
  - Environmental contaminates
    - Superior chemical resistance and performance is important
- Long-term performance history of the specific geomembrane
  - Not all membrane suppliers use the same formula, additives, processing, etc.
    - A proven formulation/process from a reputable supplier is the choice
  - Case histories of long-term performance in comparable environmental conditions
    - Select a geomembrane with a proven performance record
- Artificial weathering
  - Product specification must represent mode of failure for geomembrane
    - Artificial exposure relationship to geomembrane degradation in field
    - Sensitivity of polymer degradation to UV, OIT, moisture
    - Thermal expansion/contraction due to thermal swings induced by UV exposure

Conclusion

There are many variables to consider when specifying a geomembrane in an exposed environment. The solar radiation is the main factor that will affect the performance, based on the polymeric system. Each polymer is spectrally susceptible to specific wavelengths, in addition to environmental factors. Additives are used to retard or inhibit the molecular degradation of the polymeric matrix. To ensure long-term field performance in a variety of environmental conditions, artificial weathering, oven aging, and OIT are performed. These tests do not take into consideration all the elements that could affect the geomembrane in the field. Further, one must take into consideration heat stability, in the form of thermal expansion-contraction, and how it affects not only the membrane but also the resulting impact on the facility operation. The best option is to make selections based on the performance history of products in similar exposure conditions. For an exposed environmental application that requires a long-term, high-performance geomembrane liner or cover, contact a technical expert at Seaman Corporation. Call (800) 927-8578 for an in-depth consultation, or visit www.xr-technology.com.

References

Peggs, I.D., “Stress Cracking in HDPE Geomembranes: What It Is and How to Avoid It”, http://geosynthetica.net/tech_docs/hdpe_sc_paper.asp

Peggs, I.D., “HDPE Geomembrane Failures Return -- in Asia”, http://geosynthetica.net/news/article/2010/HDPE_FailuresInAsia_021610.aspx#

Beck, A., “Case histories of exposed geomembrane performance”, Geosynthetics, June 2011 http://geosyntheticsmagazine.com/articles/0611_f5_geomembrane_performance.html

Lustiger, A., “Understanding Environmental Stress Cracking in Polyethylene”, Medical Plastics and Biomaterials Magazine, July 1996, http://www.mddionline.com/mddi-index-ad.html?gotourl=http://www.mddionline.com/article/understanding-environmental-stress-cracking-polyethylene

Lodi, P.C., Bueno, B.S., Zornberg, J.G., “Considerations about Weathering Exposure and UV Degradation of Polymeric Geomembranes”, Minerva, 4(2): 201-205

Technical White Paper, “Thermal Degradaton of Plastics”, Zeus, 2005

Weathering Testing Guide, “Factors of Weathering and Climate”, Atlas Electric Devices Company, 2001 p. 5-17

http://engineershandbook.com/Tables/plasticthermalexp.htm

http://www.lexiscoatings.com/single-ply/