CONSIDERATIONS ABOUT WEATHERING EXPOSURE AND UV DEGRADATION OF POLYMERIC GEOMEMBRANES

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Abstract

Polymeric geomembranes can be affecting by the UV radiation in uncovered applications. They can degrade and present lost of physical and mechanical properties. UV degradation (photodegradation) is induced by irradiation with UV or visible light. The consequences of long-term exposure include discoloration, surface cracks, brittleness and deterioration in mechanical properties. This paper presents some considerations about weathering exposure of geomembranes. Exposure times, kinds of exposure, standards and some results obtained from researches are presented.

Key words: weathering exposure, UV degradation.

Introduction

All polymers are susceptible to degradation when exposed to UV radiation, heat, water and oxygen. The lifetime of a material is determined by UV radiation (photochemical degradation) and thermal oxidation, or a combination of these factors (van Santvoort, 1994).

In spite of the many advantages of the geosynthetics, they can degrade when are in contact with the sunlight in some applications. In this sense, the ultraviolet (UV) radiation is the main degradable agent of geomembranes.

This paper brings some considerations about weathering exposure and consequently UV degradation that occurs in polymeric geomembranes.

Weathering Aging and UV Degradation

Outdoor conditions may lead drastic variations in properties of a geosynthetic material due the effects of temperature and ultraviolet (UV) radiation. When this occurs, the degradation of polymers due to weathering manifests as physical and chemical changes. These processes may occur at the same time but not at the same rate. Plastic materials show some degree of difficult to be evaluating when are exposed to weathering factors. Test results of the exposed material must be taken as indicative only and exposure results can provide an indication of relative outdoor performance. In this sense, it must take in account that geographic location, temperature, wind and moisture are factors very important in the UV degradation process of polymers. The relative durability of materials in actual use conditions can be very different in different locations because of differences in UV radiation, relative humidity, temperature, pollutants, and other factors.

Haxo & Nelson (1984) summarized the weathering factors affecting durability as follows: solar radiation, temperature (elevated, depressed and cycles and fluctuations), water (solid, liquid and vapor) and normal air constituents (oxygen and ozone).

Ultraviolet radiation affects uncovered materials and it can be dangerous during the installation of the liner and before the placement of the waste, for instance. When geosynthetics are exposed to the combined influence of sunlight, rain, temperature and oxygen the UV degradation can arise and the type and intensively of ageing is caused by the UV content of the sunlight. Geosynthetics exposed to these factors starts UV degradation that is a mechanism initiated by bond scission due to wavelength that penetrated polymers and reach the molecular structure. The UV region is subdivided into UV-A (400-315 nm), which causes some polymer damage, and UV-B (315-280 nm) which causes severe polymer damage, and UV-C (280-100 nm), which is found only in outer space. Each material is sensitive to a particular wavelength (i.e. polyethylene = 300 nm, polyester = 325 nm, and polypropylene = 370 nm). The rate of ageing is also determined by the temperature and humidity. The degradation mechanism is due to molecular bond scission (in the primary polymer's backbone) created by the sensitive wavelength within the molecular structure. Ultraviolet light may also cause material embrittlement and may induce cracks depending on the intensity of the radiation. Generally, degradation is noticed as a change in color and variations in the physical properties: surface cracking and reduction of impact strength, tensile strength and elongation (van Santvoort, 1994; Reddy & Butul, 1998).

In High Density Polyethylene (HDPE) geomembranes, for instance, oxidation degradation may occur by which the molecular chains are cut off. If the oxidation starts, the molecular chains keep the degradation process. This process results in a molecular structure totally changed, decrease of mechanical resistance and stress cracking phenomenon. In Poly Chloride Vinyl (PVC) geomembranes may cause lost of plasticizers and volatiles resulting in decrease of elongation and brittle.

A solution to prevent the effect of UV degradation in PVC and HDPE geomembranes is to include some additives like carbon black and antioxidants. Carbon black is added to a geomembrane formulation mainly for ultraviolet light stabilization. The loading range of carbon black in geomembranes is typically 2% to 3% (HDPE) and 5% to 10% (PVC). Antioxidants are introduced for the purposes of oxidation prevention during extrusion and to ensure long-term service life of the product. In practice, a stabilization package is often used (Fayoux *et al.*, 1993; van Santvoort, 1994; Sharma & Lewis, 1994; Koerner, 1998; Suits & Hsuan, 2003). Some researchers (Koerner, 1998; Reddy & Butul, 1998) say that a great solution to prevent ultraviolet damage is to keep a minimum layer (15 cm) of soil, waste, or gravel over the liner so that light cannot penetrate the material.

Natural weathering tests are carried out by exposing the specimen on a suitable, inert frame with a specific slope and orientation with the north axis. ASTM standards have been used in USA and South America as a guide. After some periods of exposure samples are taken and then tensile properties are measured. Loss of these properties is taken as a measurement of degradation. The time of exposure depends upon of the purposes of the research. The ASTM D1437 (Outdoor Weathering Plastics), for example, is intended to define conditions for exposure of plastic materials to weather. It is a comparative test depending on climate, time of year, atmospheric conditions, etc, and, as such, gives only a fair indication of long term behavior. Aluminum racks are constructed with the geosynthetic to be tested fixed to them and the samples can be placed at 0, 45 or 90 degrees to the horizontal and in different solar orientations.

Another parameter commonly used is the global radiation sun energy. This parameter is very important in correlations with laboratory tests. In this sense, the weathering devices have been developed to accelerate weathering tests. This apparatus reproduce the spectrum of natural sun in UV region that is very important in ageing process when dealing with polymers. Artificial light sources (lamps) are used for laboratory simulations. They are compared with worst case conditions or the solar maximum condition. Xenon arc exposure is widely used and has been adopted for use in geotextiles. Practice G151 provides general procedures to be used when exposing nonmetallic materials in accelerated test devices that use laboratory light sources. This practice (G151) describes performance criteria for all exposure devices that use laboratory light sources and replaces practice G53, which describes very specific designs for devices used for fluorescent UV exposures. The apparatus described in Practice G53 is covered by this practice. Detailed information regarding procedures to be used for specific devices are found in standards describing the particular device being used. For example, detailed information covering exposures in devices that use carbon-arc, xenon-arc, and fluorescent UV light sources are found in practices G152, G153, G154, and G155. Practices G152, G153, G154, and G155 are performance based standards that replace Practices G23, G26, and G53.

Concerning laboratory exposure, never consider a test as a total simulation of actual used conditions in outdoor environments. Results from accelerated exposures must be considered as representative of actual exposures only when the degree of rank correlation has been established for the specific materials being tested and when the type of degradation is the same. Results from a specific laboratory test may be useful for comparing the relative durability of a material exposed in a particular exterior environment but it will not be useful for determining relative durability of the same material for a different environment.

According to Koerner & Koerner (1995) a geomembrane exposed to light is subjected to three physical phenomena: radiation, conduction, and convection. Radiation is a phenomenon in which the energy is carried by electromagnetic waves (solar radiation ranges between 0.1 to 4 mm). The transference of heat caused by a temperature gradient is known as conduction phenomenon. Convection is the transference of heat by molecular movement. The authors analyzed the behavior of field-deployed HDPE geomembranes. The first part of the study addressed the testing of black, white, textured and smooth geomembranes, exposed to field conditions throughout the year. They concluded that the temperatures in white geomembranes are always lower than those in black ones; only a small difference between the smooth and textured geomembranes exists but they noticed an advantage of the textured one, in which lower temperature was found. The second part of the study concerned with the analysis of wave occurrence due to light exposure in a 1.5 mm smooth black HDPE geomembrane. The weather conditions (sun, cloud, and wind) were the important parameters in the development of waves. Sun and no wind increased the temperatures in the membranes and the material expanded creating waves. Covering the geomembranes with a geotextile or gravel significantly reduced the temperatures and so the waves formation.

Pierson *et al.* (1993) assessed the thermal behavior of geomembranes exposed to solar radiation, which induces problems (such as wrinkles) and, even flaws at the construction stage, when the geomembrane is still uncovered by the waste. Temperatures may reach 80°C in black exposed geomembranes, such temperatures acting on material with high coefficients of thermal expansion cause wrinkles over the entire exposed surface of the geomembrane. It was found that a white coating applied on the surface of the membrane reduced considerably the overheating of the material and that the use of a geotextile over a black geomembrane only delayed the overheating, so this is not an appropriate means to eliminate long-term overheating.

The study carried out by Fayoux (1993) on PVC geomembranes which were exposed to UV light shows that the loss of plasticizers was in the order of 12 g/m^2/year. This show the importance of UV lights and stabilizers.

Cazzuffi *et al.* (1995) provided a very detailed analysis of the reason for the degradation in polymeric material due to UV light: photodegradation breaks down the chemical bonds due to UV exposure leading to cracking, chalking, color changes, or loss of physical and mechanical properties. They also compared results of laboratory and outdoor exposure tests of seven different geosynthetics. The laboratory high temperature accelerated tests were performed for periods of 1.000, 2.000, and 3.000 hours, while the outdoor tests were performed for 1.080, 2.060, and up to 17.280 hours. Geotextiles, geogrids, and geomembranes, made of PET, PP, PE, PVC, and HDPE, were tested for UV exposure effects. For geotextiles, outdoors and laboratory tests results correlated for strength: an exposure of 1.000 hours in the laboratory corresponds to one year outdoors. Such correlations are also true for geogrids and geomembranes, proving good correlation for any type of material. It was also shown that one of the main parameters for UV resistance is the thickness of the material: the thicker the material, greater the resistance. Geotextiles were subjected to embrittlement (increase of modulus up to 370%), while geogrids and geomembranes suffered a lot less to an acceptable degree. Moreover, for geogrids and geomembranes, aging is not proportional to the exposure time, and the change occurs only superficially and not in the material core.

HDPE geomembranes may be experience some levels of oxidative degradation. In this case, the polymer chains undergo reactions with oxygen leading eventually to changes in molecular structure and in morphology. As a result, critical mechanical, dielectric or esthetical properties may change beyond acceptable limits. Although oxidation reactions proceed slowly throughout the service life of the geomembrane, it is enhanced under service conditions that feed the polymer with energy (Rowe & Sangam, 2002). MFI and OIT tests can be used to evaluate the oxidative degradation. These tests are applicable only to HDPE once that PVC presents many volatiles and plasticizers in its composition.

Melt Index (MI) Test

The MFI test (ASTM D1238) is a qualitative method to assess the molecular weight of the polymer. The MFI test may be used as an indicator of oxidation. The oxidative degradation of the polymer will induce either a cross-linking reaction or a chain scission reaction in the polymer resulting in changes in molecular weight. Cross-linking reactions result in an increase in molecular weight, whereas chain scission reactions produce a decrease in molecular weight. The MFI test measures the amount of molten polymer at 190ºC extruded through an orifice with a de-fined diameter under a load of 2.16 kg in 10 minutes. A high MFI value indicates a low molecular weight, and vice-versa. Hence, the MFI value will decrease with cross-linking reactions and will increase with chain scission reactions (Hsuan & Koerner, 1998). The apparatus of MFI test is illustrated in the Figure 2. This test is only performed for HDPE since the PVC contains many volatiles and plasticizers in its composition.

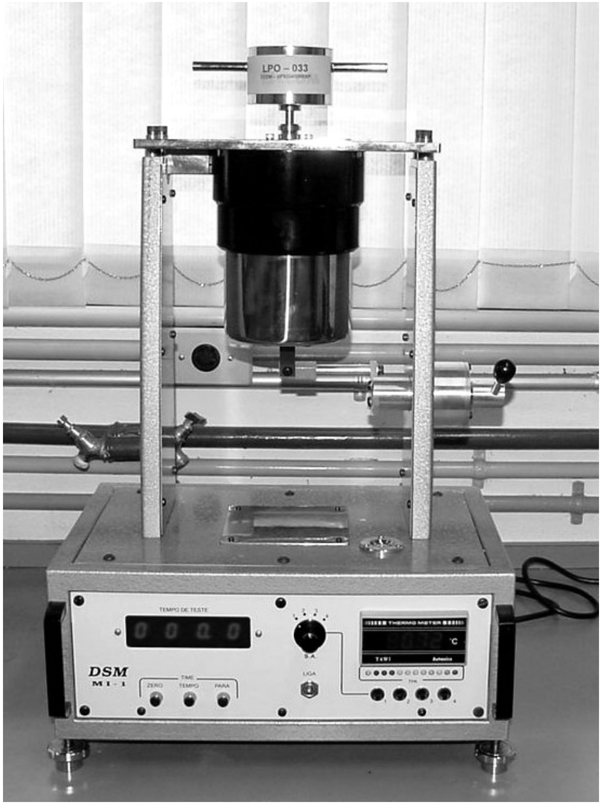

Figure 2 MFI apparathus test.

Oxidative Induction Time (OIT) Test

OIT is the time required for the geomembranes test specimen to be oxidized under a specific pressure and temperature. Since the antioxidants protect the geomembrane from oxidation, the OIT value indicates the amount of antioxidant remaining in the test specimen (Hsuan & Koerner, 1998).

The OIT tests are performed in accordance to ASTM D3895 (Standard Oxidative Induction Time – Sdt-OIT) which uses a differential scanning calorimeter (DSC) with a specimen test cell that can sustain a 35 kPa gauge pressure. The specimen is heated from room temperature to 200ºC at a heating rate of 20ºC/min under a nitrogen atmosphere. At 200ºC an isothermal condition is maintained for 5 min and the nitrogen gas is changed to oxygen gas. The test is finished when an exothermal peak occurs (oxidation of material). The minimum OIT value required is 100 minutes. For instance, the Figure 3 shows a result obtained in a HDPE geomembrane. In this case, the OIT value obtained was 8.11 minutes.

Sumary and Conclusions

This paper presented some considerations about weathering exposure and UV degradation of polymeric geomembranes. When a geosynthetic material is exposed to outdoor conditions drastic variations in properties may occur due the effects of temperature and ultraviolet (UV) radiation. Physical and mechanical properties present deterioration and the material become brittleness showing discoloration and surface cracks. ASTM standards have been used in USA and South America as a guide. After some periods of exposure samples are taken and tensile properties are measured. Loss of these properties are taken as a measured of degradation. The time of exposure depends upon of the purposes of the research. Concerning laboratory exposure, weathering devices have been developed to accelerate weathering tests. The spectrum of natural sun in UV region is reproduced using artificial lamps.

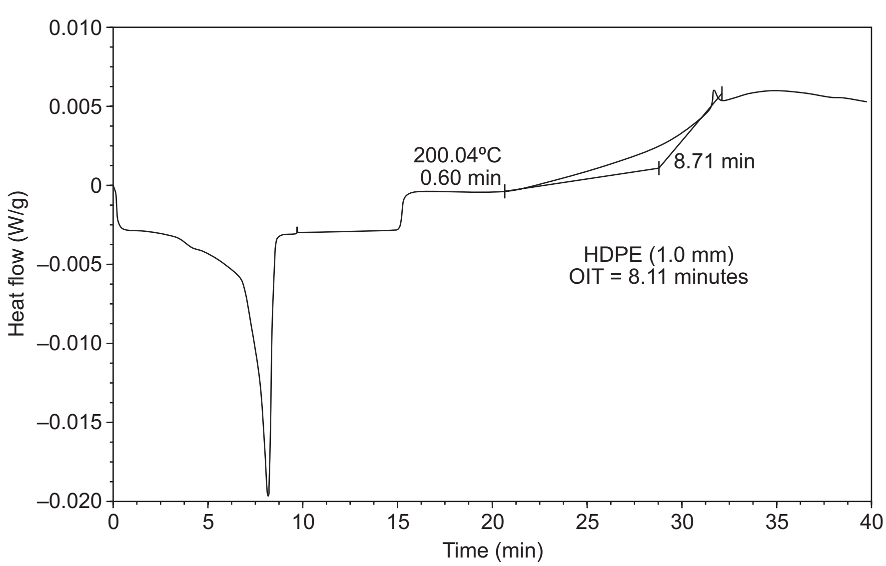

Figure 3 OIT test (1.00 mm HDPE geomembrane).

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