Geosynthetics - 7th ICG - Delmas, Gourc & Girard (eds) © 2002 Swets & Zeitlinger, Lisse ISBN 90 5809 523 1

Durability of cellular confinement systems in Quebec

D. KAY, Projects Leader, Sageos, Saint-Hyacinthe, Quebec, CANADA
D.F. SENF, Presto Products, Appleton, Wisconsin, USA
E. BLOND, Technical Director, Sageos, Saint-Hyacinthe, Quebec, CANADA
O.G. VERMEERSCH, Director, Sageos, Saint-Hyacinthe, Quebec, CANADA

ABSTRACT: An evaluation of the durability of the Geoweb® cellular confinement system has been conducted considering the environmental conditions prevailing in Quebec (Canada). The objective of the project was to evaluate if a design period of 40 years could be reasonably considered for this specific product. Aged samples were extracted from 3-to 15-year old constructions. Tensile properties, seam strengths, melt index, carbonyl index, OIT, HPOIT, carbon black content and carbon black dispersion were measured in order to determine the residual properties of these samples and to compare them with the properties of new materials. Results have shown that all samples have fully retained their functional properties. The only properties for which a variation could be observed were OIT and carbonyl index. Global analysis of the results led to the conclusion that the current resin formulation of the type of cellular confinement systems analyzed was reasonably acceptable to consider a design period of 40 years.

1 INTRODUCTION

Cellular confinement systems have been extensively used for over 20 years in civil engineering applications such as retaining walls, slope protection, channel protection and load support.

For each of these applications, the cellular confinement system may be exposed to many different environmental degradation factors. As a consequence, the resin blend used to manufacture the elementary cells has to be formulated in such a way that the panel will keep its functional properties for the entire lifetime of the structure.

In Quebec, the Quebec Ministry of Transportation (QMT) requires this type of product to be accredited for a 40-year design period. One of the basic requirements is therefore that the material itself will be able to keep its intrinsic properties for this 40-year period.

However, the principle of cellular confinement was developed in the mid 1970's and has evolved to the shape it is today. There is no standing construction in the world with an age greater than 30 years. In addition, the resin blend used to manufacture the product studied in this project was lightly modified during the past 15 years, which reduces availability of experimental data related to the actual durability of the product available today.

In this context, the QMT required the manufacturer to show that the product could resist to UV weathering effects with the conditions encountered in Quebec for at least 40 years, based on a laboratory study. The project presented in this document was thus conducted in order to define if the material had enough durability to last at least 40 years, considering the typical environmental constraints.

After identification of the resin and additives used to manufacture the specific cellular confinement system analyzed in this project, the following tasks were conducted in order to meet the objectives of the project:

1. Theoretical analysis of the mechanisms involved in the degradation of polyethylene, considering the specific additives used with the resin.
2. Identification of the type of UV exposure prevailing in Quebec.
3. Identification of construction projects with cellular confinement product exposed to similar conditions.
4. Analysis of the quality control files of the manufacturer to gather information related to the type of resin blend used to manufacture the product.
5. Sampling of aged products on pertinent locations.
6. Extensive laboratory evaluation of aged and new product.
7. Data analysis and estimation of the product durability.

2 THEORETICAL BACKGROUND

2.1 *Mechanisms involved in the degradation of polyethylene*

The deterioration of polyethylene can be caused by many mechanisms like UV degradation, thermal degradation, chemical and microbial degradation or environmental stress cracking. Relative to the high-density polyethylene used in the analyzed applications, two mechanisms predominate: thermo-oxidation and photo-oxidation.

Hsuan and Koerner (1998) reviewed the different stages of oxidation typically observed for HDPE materials (Figure 1). The thermo-oxidation is usually characterized by an induction period in which the material properties remain constant. Then, as oxidation continues, this period is followed by an acceleration period in which polymer chains react rapidly with oxygen. Typically, mechanical properties start to change after this induction period as illustrated in Figure 2.

In order to protect the polymer against oxidation, stabilizers are incorporated into the resin. In a stabilized polymer, the accelerated oxidation stage requires an even longer period of time to be reached. The stabilizers create an additional depletion time stage prior to the onset of the induction time (stage A of Figure 2). Some types of stabilizers are effective during processing (at high temperature) while others, such as Hindered Amine Light Stabilizer "HALS" protect the material for applications requiring long-term protection.

Photo-oxidation is an oxidation mechanism similar to thermo-oxidation, differing in that the source of energy is supplied by radiation instead of heat. Many variables influence the rate of degradation of polymer by photo-oxidation. The irradiance is the most important one but other factors also have an influence on the rate of degradation. Among these, the following can be listed: oxygen permeability; material temperature; moisture and rain.

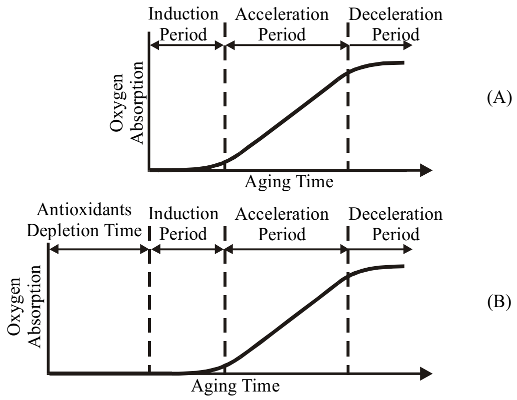

Figure 1: Curves illustrating various stages of oxidation for (a) pure unstabilized HDPE; (b) Stabilized HDPE (Hsuan et Koerner, 1998).

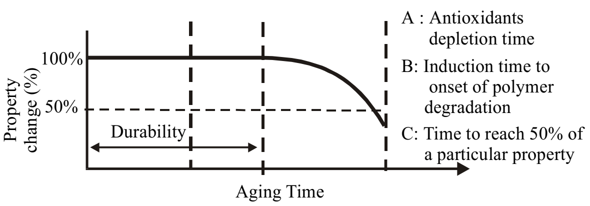

Figure 2 Three conceptual stages in chemical aging of HDPE (Hsuan and Koerner, 1998).

Considering the number of variables involved in the degradation process, one must remember that the rate of oxidation is not simply proportional to UV irradiance even if this factor is the controlling factor. As a consequence, the durability of the material is not linearly linked to the total UV radiation received by the product during its lifetime.

2.2 *Analysis of the UV irradiance actually received by cellular confinement systems*

Among all external factors influencing the durability of cellular confinement systems when exposed to UV, irradiance received by the product is one of the main factors, as long as it influences the rate of oxidation. This irradiance is dependant on the position on the earth, as shown in Figure 3.

The irradiance effectively received by a product also depends on the angle of incidence between the radiations and the surface of the product. The average annual irradiance is maximal when the surface faces south and is inclined in a way that the angle between the horizontal and the exposed surface is equal to its latitude, which is about 45^o to 50^o in the south of Quebec.

As illustrated in Figure 4, the most critical applications of cellular confinement systems with regard to UV oxidation are retaining walls. In these applications, the panels are installed horizontally, therefore the polyethylene material being exposed is vertical. The ratio 'surface area exposed to the sun / volume of polyethylene' is the highest in retaining walls, and thus the most critical.

Other factors can influence the level of irradiance received by a cellular confinement system: air pollution, presence of vegetation, snow (may be up to 5 or 6 months per year in Quebec), dust accumulation on the panels, etc. These factors typically contribute to the increase in durability of the material, as long as they screen out UV radiation.

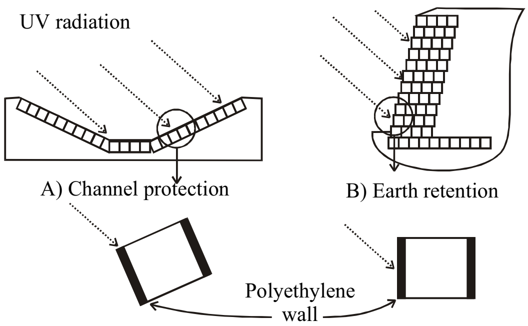

Figure 4: Relative surface of material exposed for channel protection (a) versus earth retention (b) applications.

2.3 *Monitoring of the degradation of polyethylene*

The OIT (or HPOIT) value, measured by Differential Scanning Calorimetry (DSC), is generally proportional to the stabilizer concentration for a given formulation package (Howard, 1973). During stage A illustrated in Figure 2, the OIT tends to decrease towards zero as the stabilizers are consumed.

Hsuan and Koerner (1998) have shown that a linear relation links the natural log of OIT to time during this antioxidant depletion:

$$\text{Ln (OIT)} = \text{Ln(P)} - \text{S(t)} \qquad (1)$$

Where P: initial OIT (unexposed specimen), S: Antioxidants depletion rate, t: time. This model can be used to estimate the depletion time of all the stabilizers included in the panels exposed to solar radiation. Thus the durability of the type of blend when exposed to UV radiation can be extrapolated.

Considering this background, most of this project is restricted to gathering OIT data from specimens exposed to UV radiation similar to those encountered in Quebec, and to plot the log of their OIT value with the time of exposure. This

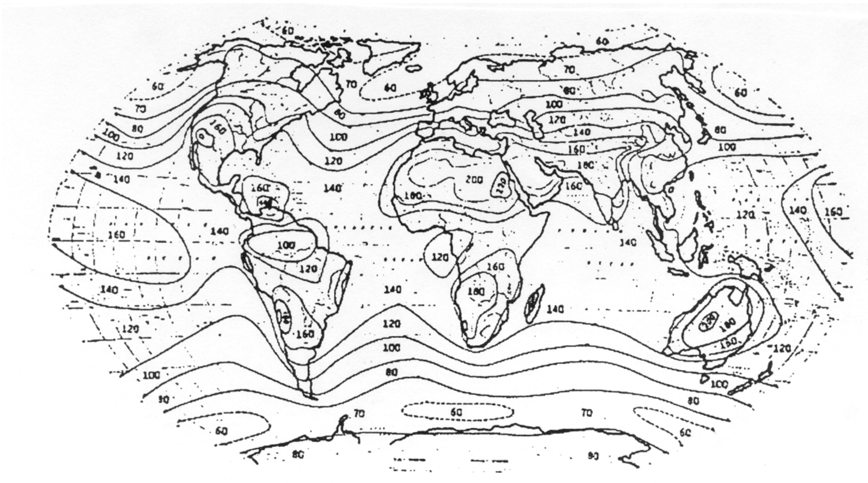

Figure 3: Average annual distribution of global irradiance on Earth (kLy)

curve can then be used to estimate the durability of the material, which is graphically measured at the point of intercept of the durability curve with the time axis ('X' axis) as shown in Figure 5.

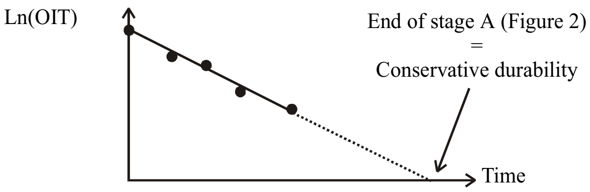

Figure 5: Graphical method used to estimate the durability of cellular confinement systems.

3 LABORATORY EVALUATION

3.1 *Selection of the samples*

Thousands of retaining walls involving cellular confinement systems were constructed around the world for the past two decades. However, projection of the durability of the material for specific conditions (i.e. Quebec) requires data gathered from samples exposed to UV in conditions similar to those in Quebec.

The problem encountered at the time of the project was that relatively few earth retention applications involving cellular confinement systems were constructed in Quebec, particularly because of the lack of accreditation of the product by the Quebec Ministry of Transportation. An accreditation partially dependant on the results of the project presented in this paper.

It was thus necessary to extend the research of construction projects to other locations with similar exposures, i.e. Northern United States and Southern Canada. Six project locations were finally selected, those being located in Quebec, Ontario and Wisconsin, with exposure time ranging between 3 and 15 years. Table 1 summarizes the types of specimens tested.

The 15-year old specimens (samples 1 and 2) were extracted from an experimental construction built in Wisconsin by the manufacturer, which was dedicated to the analysis of the product durability. This construction was free standing vertical walls located where no vegetation could grow next to the panel. As a consequence, samples 1 and 2 must be considered as being critically exposed to UV radiations.

The characteristics of each specimen were reported including the type of resin used and the type of UV stabilizer used as well as its concentration (from the quality control files of the manufacturer), the year of installation, the orientation of the specimens with respect to the sun, etc.

Finally, the recovered samples involved two types of polyethylene resin, and two types of HALS carrier with the same HALS molecule in two different concentrations for colored materials or two carbon black concentrations for black material. All samples were submitted to extensive laboratory evaluation presented below.

3.2 *Type of test conducted*

The tensile properties (ASTM D638) and melt index (ASTM D1238) were measured for all the samples. The seam resistance (peel test) and the carbonyl index (infrared analysis) were measured for both 15-year old specimens and new specimens.

In the case of weathered samples, the carbonyl index was measured at the surface exposed to the air and sun, at the surface covered by soil, and at the middle of the cellular sections in order to evaluate their level of oxidation.

OIT (ASTM D3895), carbon black content (ASTM D1603) and carbon black dispersion (ASTM D5596) were measured for black samples.

As long as HALS become ineffective at temperatures higher than 150°C, the colored samples were tested by the HPOIT method (ASTM D5885), which implies a lower temperature than OIT.

3.3 *Results*

Results of the laboratory tests are presented in Table 1. Tensile properties and melt index measured for each sample have been compared with initial values as reported in the technical data sheet of the resins. It was found that all samples had fully retained their basic properties since their installation.

Infrared analysis and OIT measurements suggest that oxidation has occurred in samples stabilized with both carbon black and HALS. A decrease of the OIT (or HPOIT) with exposure time was observed and specimens facing south presented a greater decrease than specimens facing north. The infrared analysis confirmed that oxidation begins at the surface exposed to sun and air while the surface covered by soil presents a limited level of oxidation even after 15 years of weathering.

4 DISCUSSION

4.1 *Estimation of the durability of black materials*

In the case of black products, specimens made from the same HDPE resin and containing similar carbon black content (about 2.1%) were considered. Based on the data gathered within this project and theoretical analysis, an OIT depletion time of 30 years was projected for black panels facing north, and 23 years for samples facing south.

This projected durability of samples facing south first required the projection of the material's initial OIT value, which lead to 374 minutes based on the depletion rate determined for samples facing north. It is thus believed that this projection slightly underestimates the actual durability of the product, this value being surprisingly high for this type of material. If an initial OIT of 150 minutes had been considered instead of 374 minutes, the total depletion time would have been extrapolated to 26 years.

In addition, the black material tested was installed in a location where no vegetation could grow next to the panel. This extrapolation is thus based on a very critical context, and the projected durability could be increased for more common applications.

After global analysis of the results and careful evaluation of the tests' measurements, it was concluded that black cellular confinement systems made with resin "a", with 1.5 to 2.5 % carbon black content could support the UV exposure of Quebec for a period of time in the order of 40 years.

4.2 *Estimation of the durability of colored materials*

In the case of colored cellular panels, it was found that all the specimens containing 1% of carrier B had a HPOIT value in the same range as the initial HPOIT value. As a result, the antioxidants depletion time was estimated to be significantly higher than 40 years, which lead to the conclusion that this material can be considered to last a minimum of 40 years.

The 15-year old sample (containing a higher HALS concentration) had a significantly higher HPOIT value. Even if the initial HPOIT was not measured for this sample, these results confirm that the material remains well protected against oxidation after 15 years of exposure.

Table 1: Laboratory tests results

Sample identification	1-South	1-North	2-South	2-North	3	4	5-East	5-Covered	6	7	8	9
Production year	1985	1985	1985	1985	2000	2000	1987	1987	1992	1995	1997	2000
Resin type	'a'	'a'	'a'	'a'	'b'	'a'	'a'	'a'	'a'	'a'	'a'	'b'
HALS type (1)			'A'	'A'		'B'				'B'	'B'	'B'
(or Carbon Black)	CB	CB			CB		CB	CB	CB			
Specified Concentration (%)(2)	1.5-2.5	1.5-2.5	1-2	1-2	1.5	1	1.5-2.5	1.5-2.5	1.5-2.5	1	1	1
Melt index (g/10 min)	0.12	0.12	0.12	0.11	0.31	0.17	0.14	0.15	0.2	0.19	0.17	0.32
Stress at yield (MPa)	21.4	21.1	21.1	21.3	20.1 (3)	23.8 (3)	21.8	21.4	21.6	21.9 (3)	21.9 (3)	21.0 (3)
Elongation at yield (%)	11.0	10.5	11.0	11.2	13.1 (3)	11.5 (3)	10.9	10.7	11.2	10.9 (3)	10.7 (3)	12.7 (3)
Stress at break (MPa)	33.7	32.0	30.0	31.8	20.6 (3)	19.7 (3)	28.6	29.8	28.8	24.8 (3)	27.5 (3)	21.5 (3)
Elongation at break(%)	840	840	844	878	566 (3)	346 (3)	789	842	846	668 (3)	720 (3)	562 (3)
Seams resistance (kN/m)	16.0	---	11.2	---	17.4	18.6	---	---	---	---	---	17.4
Carbon black cont. (%)	2.1	---	N/A	N/A	1.6	N/A	2.2	---	2.1	N/A	N/A	N/A
Carbon black disp.	1	---	N/A	N/A	1	N/A	1	---	1	N/A	N/A	N/A
OIT (min)	8.6	13.1	---	---	57.9	---	5.7	20.6	62.6	---	---	---
HPOIT (min)	---	---	10396	5841	---	1364	---	---	---	1180	1188	940
Carbonyl index (%)												
Face exposed to the sun	67	---	---	---	---	---	---	---	---	---	---	---
Sheet center	8	---	---	---	21	4	---	---	---	---	---	6
In contact with soil	17	---	---	---	---	---	---	---	---	---	---	---

(1): HALS 'A' is identical to HALS 'B', but in higher concentration in the carrier (2): HALS carrier or carbon black (3) Textured surface

4.3 *Influence of the direction of exposure to the sun*

The OIT of sample 1 was measured for test specimens facing both south and north. It can be noted that this carbon black stabilized material sees a higher level of degradation when exposed to the south compared to the north, which is relevant to the theory presented above.

However, the HALS-stabilized material (sample 2) does not follow this tendency. In addition, it can be noted that the measured values are extremely high. The only explanation for these observations at this time is that the HALS content of the product was significantly higher when this material was manufactured, and that it might not have been fully dispersed within the product. However, these results show that the material is in excellent shape with regard to oxidation resistance.

4.4 *Oxidation within the thickness of the product*

Test specimens of sample 1 were cut in slices parallel to the exposed face of the material, and three of these layers were submitted to Fourier-Transform Infrared (FTIR) analysis to measure the distribution of carbonyl index and to correlate this observation with the dispersion of oxidation within the thickness of the polyethylene sheet.

It was found that the middle of the panel stabilized with carbon black is still in very good shape, the external face of the cellular confinement system being more critically exposed to oxidation. It was also found that the inner face of the panel, in contact with the soil, had suffered oxidation. However, this process developed at a much lower rate than on the external face of the panel.

4.5 *Influence of oxidation on the global stability of the structure*

Analysis of the distribution of carbonyl index confirms that the oxidation rate is much greater when the material is directly exposed to the sun than when it is buried in the soil.

It can thus be observed that if the primary face of the cellular confinement panel reaches a critical level at which it loses its structural integrity, the second layer of material will not be in such a critical condition. As a result, a collapse caused by UV oxidation of a very old structure is very remote.

5 CONCLUSION

Practical application of the model proposed by Hsuan and Koerner may be difficult in a context of back calculation based on experimental data, as long as manufacturers have many different resin suppliers, and that the formulation of a specific product may be modified many times during the period the product is on the market.

The conclusions extracted from this type of analysis are specific to one type of material and should not be extended to any other type of cellular confinement system using any other type of antioxidant. In addition, the lack of control of UV exposure leads to a significant uncertainty in the prediction of the durability of the material studied within this project.

However, it was found that a design period of 40 years could be reasonably considered for the colored cellular confinement systems analyzed within this project, with regard to UV radiation prevailing in the North of USA and south of Canada, and particularly in Quebec. No apparent physical degradation could be detected after exposure time ranging from 3 to 15 years. However, part of the stabilizers contained in the resins has been consumed, as indicated by a decrease of OIT (or HPOIT).

AKNOWLEDGMENTS

Authors wish to thank the 'Ministère de l'éducation du Québec, programme de soutien aux chercheurs et chercheuses des collèges' (PSCCC)', for partially funding the travel expenses associated to the presentation of this paper.

REFERENCES

ASTM 2001. *Annual Book of ASTM Standards*, *vol. 04.09*

ASTM 2001. *Annual Book of ASTM Standards*, *vol. 08.01*

ASTM 2001. *Annual Book of ASTM Standards*, *vol. 08.02*

Hsuan, Y.G. & Koerner, R.M. 1998. 'Antioxidant Depleton Lifetime in High Density Polyethylene Geomembranes', Journal of Geotechnical and Geoenvironmental Engineering, 124 (6): 532-541.

Howard, J.B. 1973. '*Data for control of stability in polyolefin wire and cable compounds*', *Polymer Enginering Science*, 13(6): 429-434.

Gray Robert L., Lee Robert E. & Sanders Brent M. 1999. 'Aging Conditions, effect on UV Durability, Weathering of Plastics-Testing to Mirror Real Life Performance', *Plastics Design Library*, pp. 69-76.

Van Wijk W., Stoerzer M. 1986. UV Stability of Polypropylene, *Third Intern. Conf. on Geotextiles*, Vienne, Austria, pp. 851-855