Geosynthetics: Leading the Way to a Resilient Planet – Biondi et al (eds)

Effect of aged geomembrane extrusion welding on antioxidant depletion

M.M. Ali & R.K. Rowe
GeoEngineering Centre at Queen's-RMC, Department of Civil Engineering, Queen's University, Kingston, Ontario, Canada

ABSTRACT: High-density polyethylene geomembranes (HDPE GMBs) are in-situ welded to create an "impermeable seal". Extrusion welds are primarily used for repairs, curves, and other welds not accessible to fusion welding machines. A welding rod which is fed into the extrusion machine is made from the same raw materials for adherence/compatibility requirements between the two materials. The examined geomembrane was welded using preheat and barrel temperatures of 230°C and 250°C, respectively. In a municipal solid waste (MSW) landfill, an extrusion weld facing upward will be in contact with leachate that can lead to chemical degradation. In this paper, the antioxidant depletion rate from welding bead and HDPE GMB sheet away from welding immersed in MSW landfill simulation is examined over an 11-month period at 85°C, 75°C, and 65°C. Preliminary results shows that antioxidant depletion rate of the welding bead was faster than that for the GMB sheet material at lower temperatures (i.e. 65°C)

1 INTRODUCTION

High-density polyethylene geomembranes (HDPE GMBs) are an essential component of the landfill barrier system (Abdelaal *et al.* 2019; Hsuan *et al.* 2008; Morsy *et al.* 2021;). The primary function of the GMBs is to prevent the leakage of fluids and gasses over the lifespan of the landfills, which may reach from decades to centuries (Rowe *et al.* 2004; Scheirs 2009). HDPE is usually selected due to its high resistance to chemical degradation compared to other polymeric geomembranes (Koerner *et al.* 2017; Scheirs 2009). HDPE GMBs consist of 96 to 97.5% of polyethlene resin, 2 to 3% carbon black, and 0.5 to 1% of other additives (i.e., stabilizers and antioxidants) (Hsuan & Koerner 1998). The additives delayed the polymer thermo-oxidative degradation which may occur during the manufacture process, installation, and ageing (Hsuan & Koerner 1998; Scheirs 2009). During installation, HDPE GMBs rolls are welded in-situ to create continuous impermeable seal using high welding temperatures. There has not been any previous study focused on examining the effect of extrusion welding on oxidative and chemical degradation.

There are two common methods of geomembrane welding: Fusion welding and extrusion welding (Müller 2007; Scheirs 2009). Fusion welding is used for the majority of the geomembrane welding length. Extrusion welding is used for welding patches, repairs, curves, and inaccessible areas by fusion weld machines (Scheirs 2009). Although numerous studies identified welds as a weak point of the HDPE GMBs liner system (Francey & Rowe 2022a,b, c; Halse *et al.* 1990; Peggs *et al.* 2014; Rowe & Shoaib 2017, 2018), there are no studies examining the long-term performance of extrusion welding compared GMBs sheet material.

HDPE GMBs ageing follows three stages until failure is reached (Hsuan & Koerner 1998): antioxidant depletion (Stage I), where the antioxidant is depleted without a reduction

DOI: 10.1201/9781003386889-88

in the mechanical properties; induction time (Stage II), where it occurs after full depletion of the antioxidants package, and there is no change in the mechanical properties; reduction in mechanical and physical properties (Stage III), where the oxidative reactions start leading to a reduction in the mechanical and physical properties. Some work has been performed on the effect of fusion welding on the long-term behaviour of the welds. However, no studies have been performed on the effect of extrusion welds on the longevity of the welds. This study presents the preliminary results of antioxidant depletion (Stage I) for extrusion welding based on the standard oxidation time test results (Std-OIT).

2 MATERIAL

One 1.5mm HDPE GMB, denoted by MwA15, with a Std-OIT of 165± 2 (min) was examined.

The extrusion welding of MwA15 was conducted on a landfill site by a licensed geosynthetic installer on a summer day using a Demtech. The geomembrane surface was prepared by grinding the surface to remove the oxidative layers and the additive blooms. The welding machine was fed by extrusion rods made from the same geomembrane materials. The GMB sheets were preheated with hot air to reduce the heat required and increase the size of the molten bead (extrudate).

The preheating was used to avoid the thermal shock that would weaken the polymeric structure along the edge of the weld. Afterwards, the welding rod was softened, mixed in the heated barrel, and pushed out on the GMB surface. The GMB sheet was melted and mixed with the molten bead and then cooled and solidified (Peggs *et al*. 2019). The welded zone has random and isotropic microstructure (Peggs *et al*. 2019). The examined extrusion welding preheats and barrel temperatures were 220°C and 230°C, respectively.

Extrusion welds contain weld beads and flashing (squeeze out) (Figures 1 and 2). Toward the terminal of the extrusion, welding is heat affected zone, which has a similar thickness to the sheet and is subjected to high welding temperatures. The flashing (squeeze out) zones are located toward the extrusion welding extremities, which is the result of the extrudate molten polymer exiting the weld zone during welding (Figures 1 and 2).

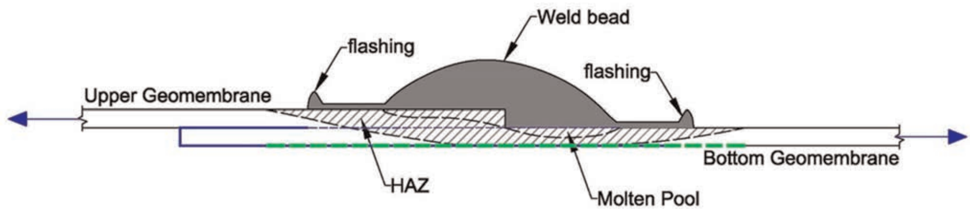

Figure 1. Cross-section of typical HDPE extrusion weld.

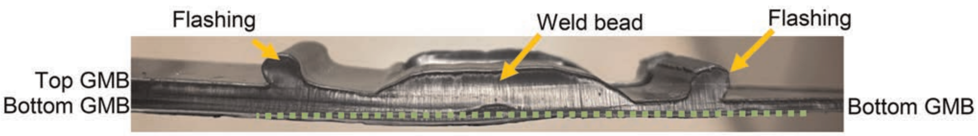

Figure 2. Photographic cross-section view of HDPE extrusion weld.

3 EXPERIMENTAL PROCEDURE

3.1 *Jar immersion*

Immersion tests were used to accelerate the ageing of the GMB extrusion welds in the laboratory. In the immersion test method, 90×170 mm welded coupons were immersed in 3.5L glass jars filled with simulated municipal solid waste leachate (MSW-Leachate 3; Abdelaal *et al.* 2014). The welded GMB coupons were separated using a glass rod to ensure that the coupons would be in contact with the leachate from both sides. The jars were placed at three different temperatures (85°C, 75°C, and 65°C). The GMB was sampled from the welding area and GMB sheet at different incubation times to monitor the change in Std-OIT with time.

3.2 *Differential Scanning Calorimetry (DSC)*

To assess the depletion of antioxidants, Std-OIT tests were conducted using a TA instruments Q-2000 series differential scanning calorimeter (ASTM D3895). First, test specimens were cut from the welding bead and sheet material. Then, the specimens were placed at the center of the aluminium pan and loaded into the DSC machine for testing. Hsuan and Koerner (1998) found that this depletion rate can be classified as a first-order decay model. The initial Std-OIT, depletion rate and residual Std-OIT are used to describe the change of Std-OIT with time for extrudate bead and SAW as follows:

$$OIT_t = OIT_o\, e^{-st} \tag{1}$$

Taking the natural logarithm of both sides of [1] gives:

$$\ln(OIT_t / OIT_o) - st \tag{2}$$

where OIT_t is the Std-OIT during ageing at time t (min); OIT_o is the initial Std-OIT (min); s is the antioxidant depletion rate (month^{-1}); t is the incubation time (month).

4 RESULTS

4.1 *Unaged Std-OIT*

Std-OIT was examined for aged and unaged GMB sheets and post-welding bead zone. The unaged Std-OIT of welding rod material was measured before feeding it into the welding machine to investigate the effect of welding temperature on the pre-welding bead. The measured unaged Std-OIT of welding rod material (348±16 min) was more than twice the Std-OIT of the unaged sheet material (165± 2 min). The high Std-OIT value of unaged pre-welded rods was due to using a high antioxidant package to decrease the effect of the high welding temperature on the possibility of reduction of Std-OIT of the unaged post-welded area. After welding, the Std-OIT of the extrudate bead was 181± 1 min, and this follows from it being twice initially and ~10% finally (after welding) above that of the sheet away from the weld (SAW). The post welding Std-OIT of the sheet and extrudate bead were higher than the minimum requirement (100 min) indicated by GRI-GM 13.

4.2 *Depletion in oxidative induction time*

The Std-OIT obtained from specimens taken from extrudate bead and sheet material immersed in MSW Leachate at three different temperatures (85°C, 75°C and 65°C) over 12 months of immersion were normalized based with respect to the initial Std-OIT value and plotted for the two locations examined in (Figure 3). The depletion was fastest in the GMB sheet material and slowest at the welding bead (where the geomembrane was thick) at 85°C (Figure 3). The depletion rates decreased with decreasing the temperature (Figure 3). At low temperatures (i.e., 65°C), the rate of depletion of the extrudate bead area (where the extrudate rod was molten and pushed into the geomembrane during the welding process) was faster than at the geomembrane sheet away from welding (SAW) (Figure 3).

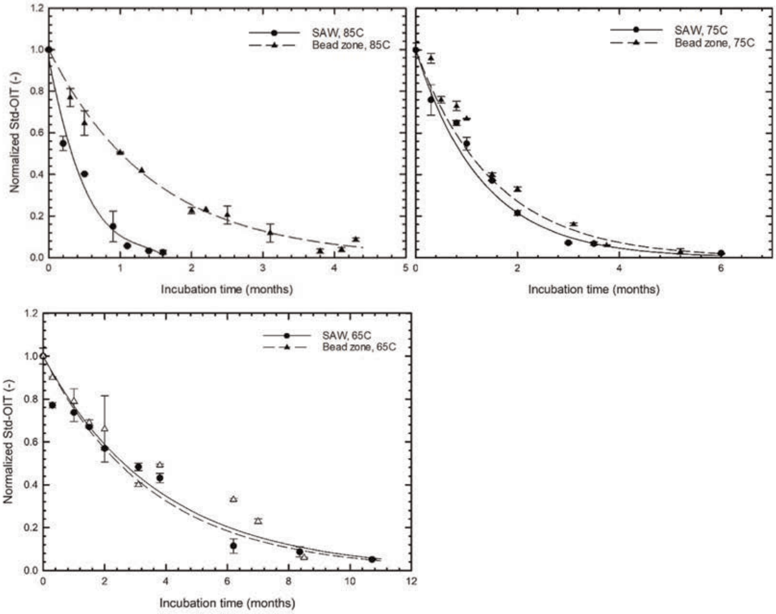

Figure 3. Normalized variation of Std-OIT of bead zone and sheet material with incubation time at two locations immersed in Leachate 3 at 85°C, 75°C, and 65°C.

The welding bead Std-OIT depleted to residual after four months at 85°C, five months at 75°C, and 10.5 months at 65°C. The sheet material Std-OIT depleted after 1.5 months at 85°C, five months at 75°C, and ten months at 65°C. Despite the higher initial Std-OIT of the extruding rod, the depletion rate was slow for the welding bead at 65°C, and the fastest rate was for the welding bead area at 85°C com to the pared sheet away from welding (SAW).

A trend of exponential decay was observed at all temperatures (Figure 3). Figure 4 is plotted as ln (normalized Std-OIT) to allow linear regression to be conducted.

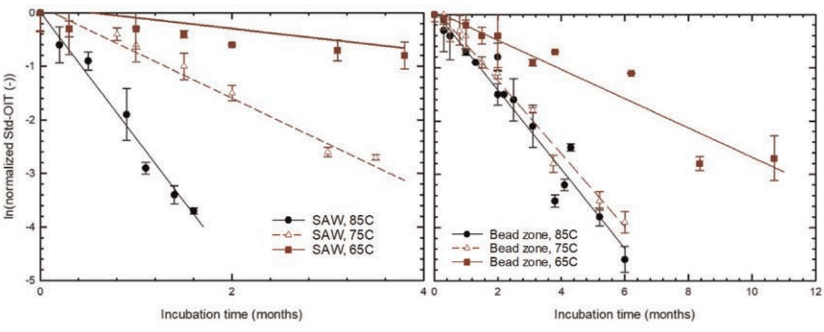

Figure 4. Linear regression of ln (Std-OIT (min)) depletion of sheet material and bead zone, aged at 85°C, 75°C, and 65°C.

Arrhenius model was used to predict the Std-OIT depletion rates at lower temperatures (i.e., typical landfill temperature). The predicted (based on Eqs. 1 and 2) Std-OIT depletion times are summarized in Table 1, which shows that the time to antioxidant depletion was lowest for the extrudate bead at lower temperatures.

Table 1. Predicted time to Std-OIT deletion in bead and sheet away from the weld (SAW).

	Predicted Depletion time (years)	
Temp. (°C)	Bead (220°C/230°C)	SAW
85	0.4	0.16
75	0.6	0.4
65	0.9	1.2
55	1.4	3.6
40	3	21
35	3.9	40
30	5.2	76

The predicted Std-OIT depletion time in MSW Leachate 3 at a typical landfill temperature of 30°C–40°C (Rowe 2005) was 5.2 to 3 years for the extrudate bead and 76 to 21 years for the geomembrane sheet material. The examined geomembrane showed a depletion rate in the extrudate bead (≥ 7 times) faster than in the sheet material. The depletion rates incubated in jars for sheet material have been shown to be substantially faster than in a composite liner system and may be 3.4-fold (or more; (Rowe *et al.* 2010, 2020) greater than in immersion tests (e.g., as given in Table 1) The same comparison has no been done for welds but that depletion can also be expected to be much slower than in Table 1in the filed, however the relative trend is suspected to be similar.

5 CONCLUSIONS

This paper has focused on the effect of extrusion welding on the antioxidant depletion from extrusion welds for a 1.5 mm HDPE GMB used in municipal soil waste applications. The extrusion welds performed on sheet at a temperature of 37°C for a combination of pre-heating and barrel temperatures of 220°C and 230°C. Accelerated ageing tests at 85°C, 75°C, and 65°C were conducted to increase the antioxidant depletion rate and the Arrhenius model was then used to predict the antioxidant depletion rate expected in the field. For the conditions considered, the following preliminary conclusions have been reached for the GMB sheet and extrudate bead:

(1) The unaged post-welding Std-OIT of the extrudate bead was higher than the same for SAW for the GMB examined.
(2) At a test temperature of 85°C, the Std-OIT depletion rate of the extrudate bead was slower than SAW immersed in MSW Leachate; this is attributed to the greater thickness of the extrudate bead compared to the SAW.
(3) The Std-OIT depletion rate of the extrudate bead was faster than SAW at a lower temperature (i.e. 65°C).
(4) The predicted antioxidant depletion times to the residual value for the GMB immersed in MSW leachate at a temperature of 35°C was 3.9 years for welding bead and 40 years for the geomembrane sheet (and probably 3-4 times longer in a full barrier system).

This paper only reported antioxidant depletion detected by Std-OIT test for one geomembrane and one welding combination. An examination of the effect of different welding parameter combination on antioxidant depletion of welding bead and heat affected zone is important. Additionally, the effect of extrusion welding on physical and mechanical properties needs to be examined for unaged and aged extrusion welds specimens.

ACKNOWLEDGEMENTS

The research described here was supported by NSERC strategic grant STPGP 521237 – 18 and the Geosynthetic Institute (GSI) fellowship grant. The equipment used was funded by Canada Foundation for Innovation (CFI) and the Government of Ontario's Ministry of Research and Innovation.

REFERENCES

Abdelaal, F. B., Rowe, R. K., Smith, M., & Thiel, R. 2011. OIT Depletion in HDPE Geomembranes Used in Contact With Solutions Having Very High and Low pH. In *Proceedings of the 14th Pan-American Conference. Soil Mechanics and Geotechnical Engineering*, Toronto, Ontario: 2–6.

Abdelaal, F.B., Rowe, R.K. & Islam, M.Z. 2014. Effect of Leachate Composition on the Long-term Performance of a HDPE Geomembrane. *Geotextile and Geomembranes* 42: 348–362.

ASTM D3895. *Standard Test Method for Oxidative Induction Time of Polyolefins by Differential Scanning Calorimetry*. Annual Book of ASTM Standards, Philadelphia, USA

ASTM D5199. *Standard Test Method for Measuring the Nominal Thickness of Geosynthetics.* Annual Book of ASTM Standards, Philadelphia, USA.

ASTM D 6392. *Standard Test Method for Determining the Integrity of No Reinforced Geomembrane Seams Produced Using Thermo-fusion Methods.* Annual Book of ASTM Standards, Philadelphia, USA.

Ewais, A. M. R., Rowe, R. K., Brachman, R. W. I., & Arnepalli, D. N. 2014. Service Life of a HDPE GMB Under Simulated Landfill Conditions. *J Geotech. Geoenviron.* 140(11): 04014060.

Francey, W. & Rowe, R.K. 2022a. Stress Crack Resistance of Unaged HDPE Geomembrane Fusion Seams. *Geosynthetic International.*

Francey, W. & Rowe, R.K. 2022b. Long-term Stress Crack Resistance of HDPE Fusion Seams Aged at 85°C in Synthetic Leachate. *Can. Geotech. J*, in press

Francey, W. & Rowe, R.K. 2022c. Thickness Reduction - Squeeze-out Std-OIT Loss Relationship for HDPE Geomembrane Fusion Seams. *Geotext. Geomembr.*, in press

Giroud, J. P. 2005. Quantification of Geosynthetic Behaviour. *Geosynthetics International*

GRI-GM13. 2003. *Standard Specification for Test Properties, Testing Frequency and Recommended Warrant for HDPE Smooth and Textured Geomembranes*. GRI, Folsom, Pennsylvania, USA.

GRI-GM19. 2005. Standard Specification for Seam Strength and Related Properties of Thermally Bonded Polyolefin Geomembranes. GRI, Folsom, Pennsylvania, USA.

Hsuan, Y. G. & Koerner, R. M. 1998. Antioxidant Depletion Lifetime in High-Density Polyethylene Geomembranes. *ASCE J Geotech. Geoenviron*. 124(6): 532–541.

Kavazanjian, E., Andresen, J. & Gutierrez, A. 2017. Experimental Evaluation of HDPE Geomembrane Seam Strain Concentrations. *Geosynth. Int*.

Müller, W.W 2007. Welding of HDPE Geomembranes. *HDPE Geomembranes in Geotechnics* 2007: 379–420.

Müller, W. & Jacob, I. 2003. Oxidative Resistance of High-density Polyethylene Geomembranes. *Polymer Degradation and Stability* 79(1): 161–172.

Rowe, R.K., & Sangam, H.P. 2002. Durability of HDPE Geomembranes. *Geotextile and Geomembrane* 20(2): 77–95.

Rowe, R. K., Quigley, R. M., Brachman, R. W. I. & Booker, J. R. 2004. *Barrier Systems for Waste Disposal Facilities*, E & FN Spon, London.

Rowe, R.K., Islam, M.Z. & Hsuan, Y.G. 2008. Leachate Chemical Composition Effects on OIT Depletion HDPE GMB. *Geosynthetic International* 15: 136–151.

Rowe, R. K., Rimal, S., & Sangam, H. 2009. Ageing of HDPE Geomembrane Exposed to Air, Water and Leachate at Different Temperatures. *Geotextile and Geomembrane* 7(2): 137–151.

Rowe, R.K, Islam, M.Z. & Hsuan, Y.G. 2010. Effect of Thickness on the Ageing of HDPE Geomembranes. *ASCE J Geotech. Geoenviron*. 136(2): 299–309.

Rowe, R.K., Islam, M.Z., Brachman, R.W.I., Arnepalli, D.N. & Ewais, A.R. 2010. Antioxidant Depletion from an HDPE Geomembrane Under Simulated Landfill Conditions. *ASCE J Geotech. Geoenviron*. 136: (7): 930–939.

Rowe, R.K., & Shoaib, M. 2017. Long-term Performance HDPE Geomembrane Seams in MSW Leachate. *Can. Geotech. J*. 54(12): 1623–1636.

Rowe, R.K. & Shoaib, M. 2018. Durability of HDPE Geomembrane Seams Immersed in Brine for Three Years. *J Geotech. Geoenviron*. 144(2).

Rowe, R.K., Abdelaal, F.B., Zafari, M. Morsy, M.S. & Priyanto, D.G. 2020. An Approach to Geomembrane Selection for Challenging Design Requirements, *Can. Geotech. J.*, 57(10):1550–1565.

Peggs, I. D. 2019. Impact of Microstructure on HDPE Geomembrane Seaming and Vice Versa. *Geosynthetics*. Houston, TX, USA.

Sangam, H.P. & Rowe, R.K. 2002. Durability of HDPE Geomembranes - A Review. *Geotextile and Geomembrane* 20(2): 77–95.

Scheirs, J. 2009. *A Guide to Polymeric Geomembranes: A Practical Approach*. Australia: John Wiley and Sons, Ltd.

Zhang, L., Bouazza, A., Rowe, R. K., & Scheirs, J. 2017. Effect of Welding Parameters on Properties of HDPE Geomembrane Seams. *Geosynthetics International* 1(11).