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

Effect of welding quality from dual track wedge welding on post-weld geomembrane oxidative induction time

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ABSTRACT: Geomembranes sheets used in fluid containment applications are welded together in situ using a dual track hot wedge welder or extrusion welding. In dual track wedge welding, overheating can occur in the weld and still meet typical acceptance standards based on peel and shear strength. However, this overheating depletes antioxidants and contribute to a potential reduction in the service life of the geomembrane in the heat-affected zone (HAZ) and junction zone (JZ) adjacent to the weld. This study examines the relationship between the welding quality and thickness on the production of the weld and any reduction in standard oxidative induction time (Std-OIT) for four HDPE geomembranes. The paper describes ageing tests being conducted on these different welds to evaluate the impact of ageing on the rate of antioxidants depletion during welding on the aging of the junction zone relative to the parent material.

1 INTRODUCTION

The composite liners using a geomembrane over a geosynthetic clay liner (GCL) are extensively used to minimize the migration of contaminants from solid waste landfill facilities (Abdelaal et al. 2019; Abdelaal & Rowe 2019; McWatters et al. 2020; Rowe 2005). However, the correct performance of the composite liners lies on the correct choice and installation of the materials with a service life that will need to exceed the contaminating lifespan (centuries). Previous studies have examined the degradation rates and service life of HDPE geomembranes for a wide variety of conditions (Abdelaal & Rowe 2019; Ewais et al. 2014; Li et al. 2021; McWatters et al. 2020; Morsy & Rowe 2020). Geomembranes are known to age at varying rates depending on the material, time, exposure medium, temperature, and strain, with brittle failure, or stress cracking, being the final failure mechanism. Researchers have examined the durability of HDPE geomembranes focusing on sheet durability. However, one of the essential processes involving the use of geomembranes as barriers, namely the welding of panels together, has been neglected in most studies. Available evidence suggests that the welds/seam are the most consistent weak point (Francey & Rowe 2021; Giroud 2005; Kavazanjian et al. 2017; Peggs et al. 2014; Rowe & Shoaib 2017, 2018; Zhang et al. 2017). Thus, this paper will follow on form the limited work to date by examining the effect of welding on the rate of antioxidant depletion in the junction zone (JZ) relative to the parent material for four different geomembrane thickness welded with two different sets of welding parameters. The junction zone (JZ) represents the intermediate area between the weld zone (WZ) and heat affected sheet zone (HAZ) as shown in Figure 1.

DOI: 10.1201/9781003386889-60

1.1 *Seams*

The wide use of HDPE geomembranes requires the application of weld techniques to construct a uniform barrier. There are different methods of geomembrane welding: extrusion fillet welding, extrusion flat welding, dual track wedge weld, and hot air welding. The current practices commonly use the dual track wedge and the extrusion welds due to the fast process and control. The dual track wedge welding consists of applying pressure to two parallel tracks of heated geomembrane and forming two welds with an air channel between the two. This air channel can be used to perform integrity tests after the welding process. During the welding process, the technician can change the machine's speed, temperature, and pressure based on environmental conditions and the thickness of geomembrane. These parameters should be validated using destructive tests and trial seams. If these welding parameters are not correctly defined, poor seams and localized defects can occur as the result of over or under-heating the weld itself (Elton & Peggs 2002; Müller 2007; Scheirs 2009; Zhang et al. 2017). The current definition of a good and bad geomembrane weld is based on the ASTM 6392 recommendations and German DVS 2225-4. However, while these guidelines are useful for construction monitoring, they have limited applicability with respect to the long-term performance of seams. There has been a paucity of studies examining the durability of HDPE seams, with a few notable exceptions. Rowe & Shoaib (2013, 2017) found that the heat-affected zone (HAZ) represents a critical location of the weld with respect to ageing, with faster antioxidant depletion. Kavazanjian et al. (2017) experimentally showed the level of strain concentration that occurs at seams. Francey & Rowe (2021) analyzed the stress crack resistance of HDPE seams exposed to synthetic leachate at 85°C and demonstrated that the stress crack resistance of seams is affected by the welding parameters and why these can make a weld the critical weaker point with respect to liner durability.

1.2 *Ageing process and immersion tests*

Oven immersion tests are commonly used to examine the stages of geomembrane degradation and to allow extrapolation of HDPE geomembrane behaviour at any site-specific temperature (Abdelaal et al. 2019; Abdelaal & Rowe 2019; Hsuan & Koerner 1998; McWatters et al. 2020; Morsy & Rowe 2020; Rowe et al. 2009, 2010a; Sangam & Rowe 2002). The exposure to elevated temperatures and synthetic MSW leachates reduce the time to chemical degradation of geomembranes. During these tests, three stages can be observed: (a) antioxidant depletion (Stage I), where antioxidants in the geomembrane have just depleted to a residual value; (b) induction period (Stage II), where additives have been fully depleted but mechanical degradation has not yet occurred; and (c) reduction in mechanical properties (Stage III), where thermo-oxidative degradation leads to a reduction in mechanical properties (Hsuan & Koerner 1998; Rowe & Sangam 2002). The life service of the geomembrane can be improved with either a change in the additives to increase Stage I or the resin to increase Stages II & III. However, the focus in both cases is on increasing the service life of the sheet. The portion of the sheet that is welded is subject to elevated temperatures to melt the geomembrane and produce the weld, with the normal wedge temperature ranging between 350-560°C; much higher than the effective temperature range of common antioxidants (Hsuan & Koener 1998). The implications of this are not well understood.

2 MATERIAL AND EXPERIMENTAL PROCEDURE

2.1 *Geomembrane properties*

Table 1 presents the initial properties of four HDPE geomembranes examined. These geomembranes were dual wedge-welded by an experienced technician at ambient temperature (20°C) using two different machines: DemTech ProWedge (DPW) and Leister G7 (G7). The welding parameters are presented in Table 2, following the guidelines of the welding machine manufacturer and the qualification tests (peel and shear). “Good” and “Inferior” welds were prepared, changing the properties to produce rippling for the inferior welding quality.

Table 1. Initial properties of HDPE geomembranes.

Index Property Geomembrane	Initial Value			
	MxC10	MxC15	MxC20	MxC24
Thickness (mm)	1.0	1.5	2.0	2.4
Std-OIT (min)	155	160	162	162
HLMI (g/10min)	17.3±0.6	15.3±0.2	15.7±0.7	16.3±1.1

Table 2. Initial properties of HDPE seams.

Geomembrane	MxC10		MxC15		MxC20			MxC24
Welding quality	Good	Inferior	Good	Inferior	Good	Inferior	Good	Inferior
Welding Speed (m/min)	3.0	1.8	5.5	3.7	5.0	2.6	3.2	1.6
Wedge Temperature (°C)	400	460	400	460	400	455	420	460
Welding Pressure (N)	-*	-*	1060	1060	1200	1200	1300	1300
Sheet ayay form weld-OIT (min)	155	155	160	160	162	162	162	162
Std-OIT (min) JZ (see Figure 1)	157	147	161	157	156	160	160	161
Std-OIT (min) WZ (see Figure 1)	153	153	161	157	161	161	149	154
Average Weld Thickness (mm)	1.90±0.07	1.69±0.09	2.40±0.05	2.03±0.12	3.35±0.17	2.93±0.12	3.90±0.07	3.11±0.06
Thickness reduction (mm)	0.1	0.31	0.6	0.97	0.65	1.07	0.9	1.69
Thickness reduction (T_R) limits (mm)	-		$0.6 \leq T_R \leq 0.8$		$0.4 \leq T_R \leq 0.8$		$0.4 \leq T_R \leq 0.8$	

*Welded with DPW which does not quantify pressure but has a number of specific settings.

2.2 *Qualification tests*

After the welding, the welds were tested following the current North American guideline (ASTM 6392). The criteria defined by ASTM D6392 require a specified value for peel and shear strength and elongation. For all four geomembranes and two welding qualities examined the seams passed the tests. Thus, seams welded considered to have inferior quality passed the usual quality control tests despite evidence of overheating in the form of rippling. Additionally, to the ASTM 6392 guidelines, the seams were evaluated by the DVS 2225-4 which has a thickness reduction criterion for the weld. The welds produced with inferior welding quality did not meet this criterion. For MxC10 it was not possible to produce a viable weld with a thickness reduction higher than 0.3.

2.3 *Immersion test*

After the welding process, qualification tests the four geomembranes were cut in coupons (190 ×95 mm) and immersed in synthetic leachate in 4-litre glass jars. The coupons were separated by 5 mm glass rods to ensure exposure to the fluid on both sides of geomembrane coupons. They were all incubated at 75°C and 85°C where chemical degradation requires a short time. These samples were used to extract specimens for OIT tests at different times of ageing. The synthetic leachate solution used in this research is based on studies conducted by Rowe et al. (2009), Abdelaal et al. (2014b), and Rowe & Shoiab (2013, 2017). This solution is based on the chemical analyze conduct for the Keele Valley landfill, in Ontario, Canada (Rowe et al. 2009). Rowe and Shoiab (2017) conducted research using this leachate to examine the long-term durability of HDPE seams.

As a result of chemical degradation, there can be a loss of antioxidants or stabilizers from the geomembrane. To evaluate this change Std-OIT tests were performed using a TA instruments Q-200 series differential scanning calorimeter (DSC). The OIT specimens were taken at the three locations shown in Figure 1: (1) The Sheet Away from the Weld (SAW), where the geomembrane is unaffected by the welding process; (2) The Welded Zone (WZ) below the nip rollers which has experienced some thickness reduction (see Table 2); and (3) The Junction Zone (JZ) adjacent to the weld that includes some squeeze-out fused to and integral with the sheet on neither side by heat of the welding process and having a thickness greater than either the sheet or the Welded zone (WZ). This is the first study to examine the JZ; others have focused on the HAZ.

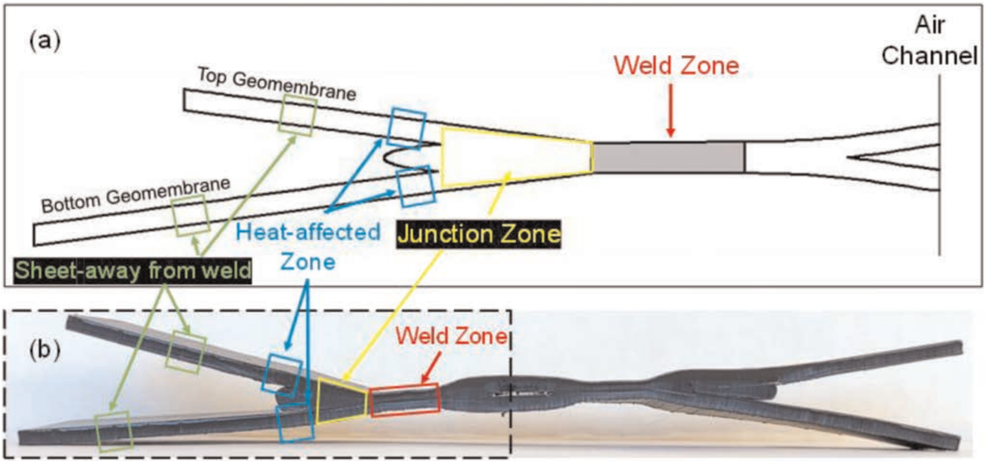

Figure 1. Cross-section of typical HDPE dual track fusion weld (a) Schematic magnification of main zones, (b) Entire cross-section of the weld.

3 PRELIMINARY RESULTS

Std-OIT depletion was examined for four different geomembranes and two welding qualities, during the tests three different areas were analyzed for 16 weeks and two immersion temperatures (75°C and 85°C). Figure 2 presents Std-OIT results for MxC10 and MxC15 for both welding quality parameters with time, normalized by dividing the values by the initial (virgin) material values immediately after welding.

The observed results for MxC20 and MxC24 were similar to those shown in Figure 2 for thinner geomembranes. Based on these preliminary results the STD-OIT depletion of the antioxidants was fastest in SAW, next in the WZ and slowest in the JZ. This general trend was found for all the thicknesses for both sets of welding quality parameters and both immersion temperatures analyzed. The difference in welding quality is evident from faster Std-OIT depletion for the inferior welds than for the good welds. This effect decreased slightly with an increase in geomembrane thickness.

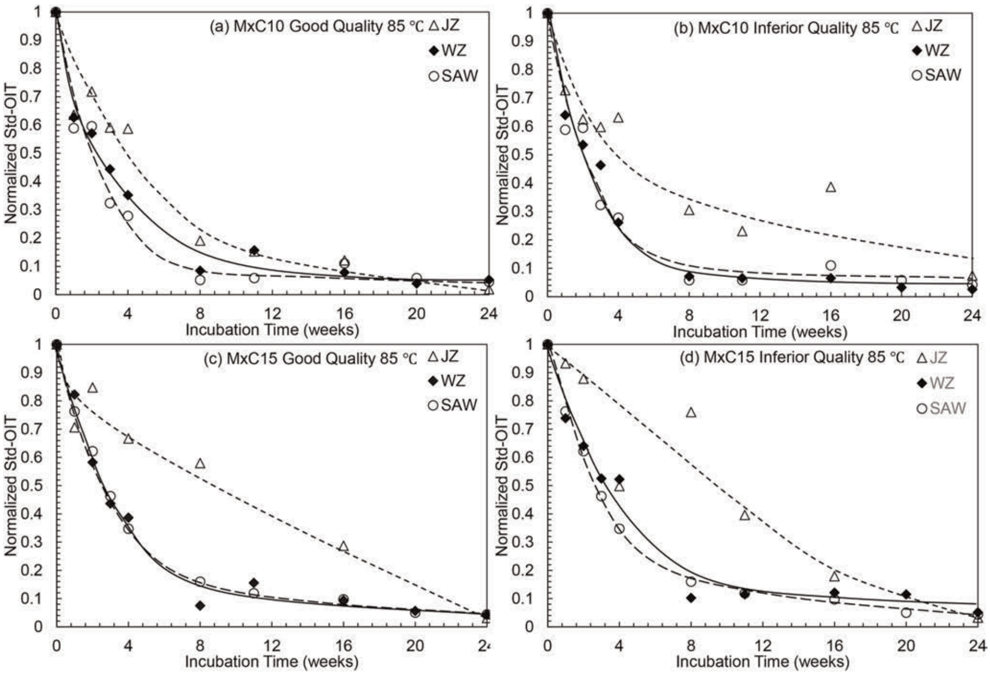

Figure 2. Normalized variation Std-OIT with incubation time at three locations immersed in leachate at 85 °C (a) MxC10-Good weld, (b) MxC10-Inferior weld, (c) MxC15-Good weld, and (d) MxC15-Inferior weld. Note: SAW is the same for good and poor for each GMB thickness and can be used as a reference curve.

The slower depletion of the junction zone (JZ) compared with weld (WZ) and the parental sheet (SAW) is attributed to the difference in geomembrane thickness at each location because an increase in thickness results in a longer path for the outward diffusion of antioxidants (Rowe et al. 2010, Rowe et al. 2014, Rowe & Ewais 2014). The fast depletion of SAW than WZ is in agreement with the findings of Rowe & Shoaib (2017) and Rowe & Shoaib (2018). Also, it is important to highlight that this study and Rowe & Shoaib (2017, 2018) used different HDPE geomembranes with different additives packages and properties. Longer incubation times are needed to more accurately compare the JZ and HAZ in terms of antioxidant depletion.

4 CONCLUSIONS

This paper has reported an examination of the effect of geomembrane thickness and welding quality on the Std-OIT depletion for three different regions of the weld. The preliminary results suggest the following conclusions for the four different geomembranes and two welding quality parameters examined in this paper.

- Std-OIT depletion was fastest for the SAW and WZ and slowest for JZ, showing that for the material and data analyzed to date, the JZ is not a critical zone with respect to antioxidant depletion.
- Welding quality appears to have a significative effect on the Std-OIT depletion rate for all the geomembrane and temperatures studied. The influence of welding quality on results appears to be reduced with increasing geomembrane thickness.

- The inferior welding quality that visibly presented some sign of overheating and rippling met typical QA/QC peel and shear test requirements.

These preliminary findings will be re-examined as more data becomes available.

ACKNOWLEDGMENTS

This research is part of a broader study being conducted at Queen's University with financial support from the Natural Sciences and Engineering Research Council of Canada.

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