GEOANZ #2

HDPE geomembrane welding with dual track fusion seams, why strength isn't the only thing to be checking

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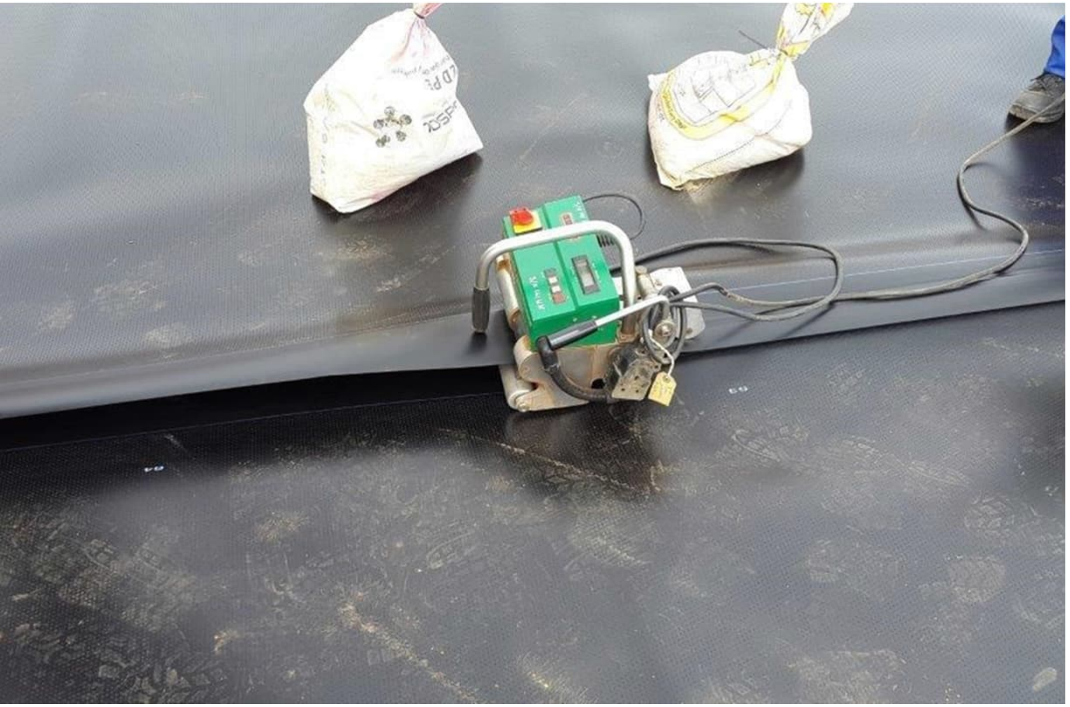
HDPE geomembrane welding with dual track fusion seams

- HDPE geomembranes are deployed as rolls of sheet material that require seaming (often in the form of fusion welding) in the field to provide a continuous hydraulic barrier



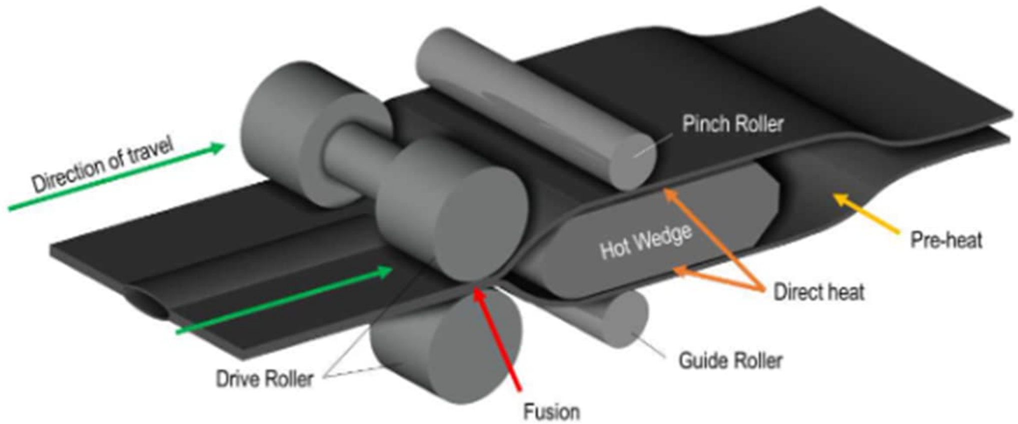
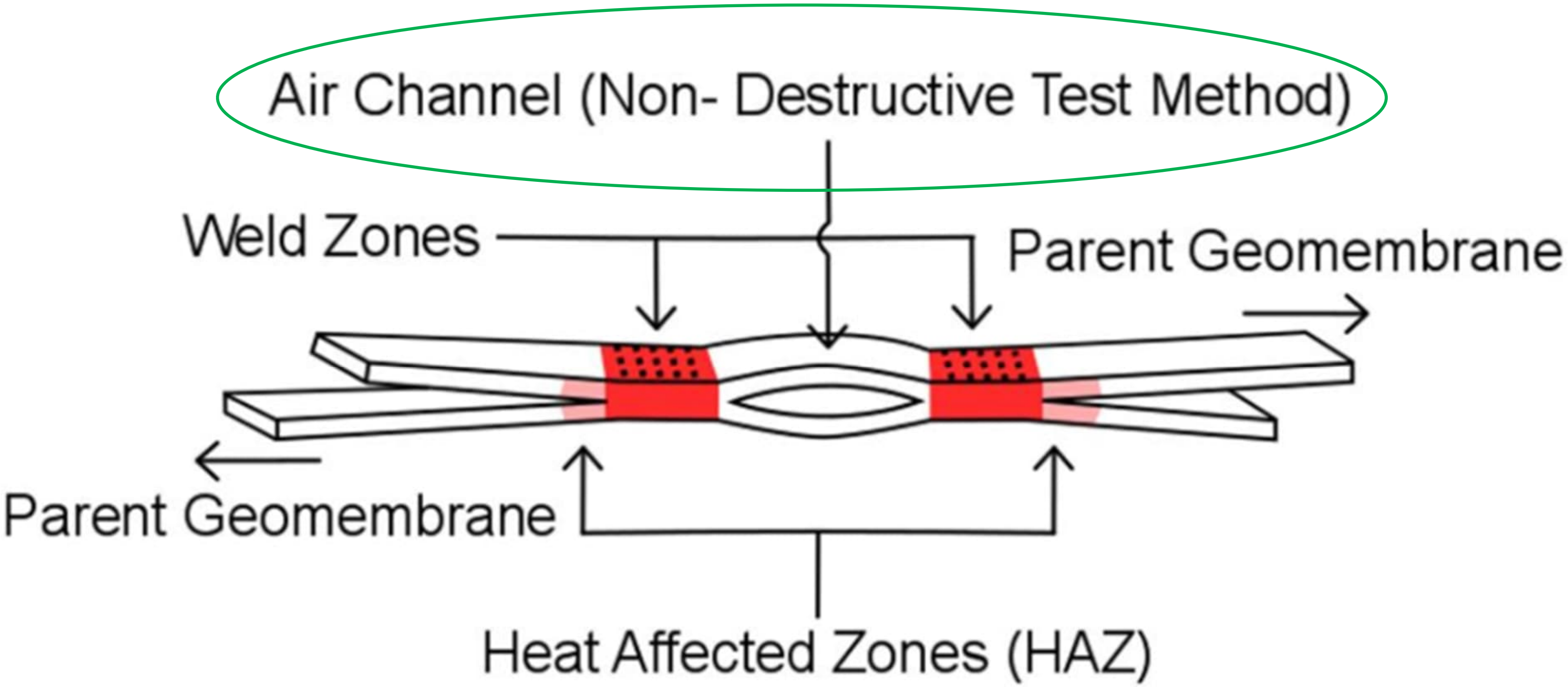


Image from – SEL Environmental- https://www.geomembrane-installation.co.uk

Dual track fusion seam



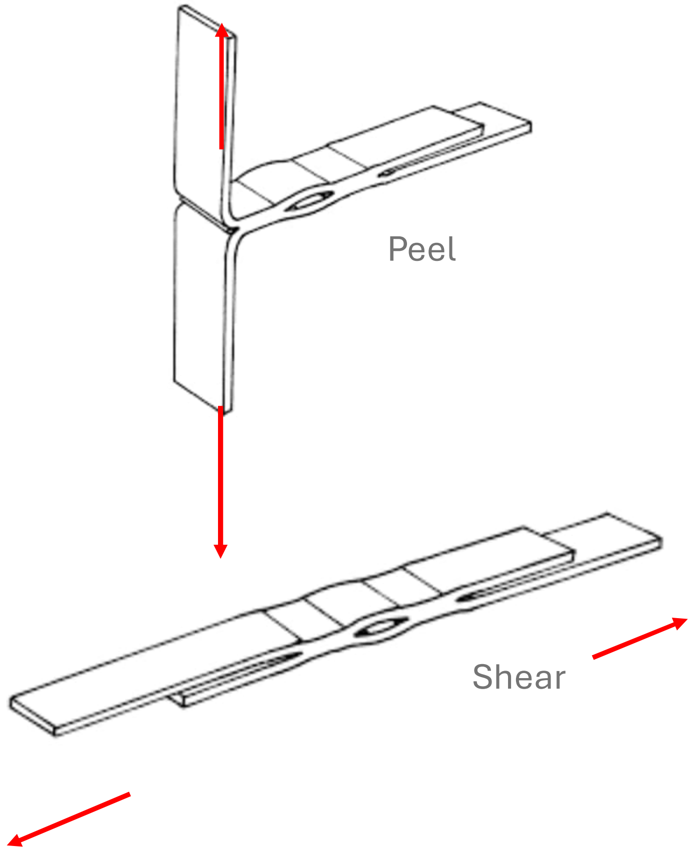
A seam's HAZ begins where the parent sheet, adjacent to the weld, is subjected to relatively high heat during seaming

Image from - Effect of dual track wedge welding at 30°C ambient temperature on post-weld geomembrane oxidative induction time – Rowe, Francey 2018, Proceedings of the 11th International Conference on Geosynthetics

Air channel pressure testing

Trial welds and destructive testing conducted according to GRI GM19

GEOANZ #2



GRI GM19 – for testing trial and destructive welds

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GRI GEI GII GSI GAI GCI

Original: February 28, 2002
Revision 10: March 18, 2021
Revision schedule is on pg. 12

GRI -GM19a Standard Specification*

Standard Specification for

"Seam Strength and Related Properties of Thermally Bonded Homogeneous Polyolefin Geomembranes/Barriers" SM

Trial weld and destructive tests are typically conducted every 150 m of welding

Table 1(b) – Seam Strength and Related Properties of Thermally Bonded **Smooth and Textured** High Density Polyethylene (HDPE) Geomembranes **(S.I. Units)**

Geomembrane Nominal Thickness	0.75 mm	1.0 mm	1.25 mm	1.5 mm	2.0 mm	2.5 mm	3.0 mm
Hot Wedge Seams[1]							
shear strength, N/25 mm.	250	350	438	525	701	876	1050
shear elongation at break[2], %	50	50	50	50	50	50	50
peel strength, N/25 mm	197	263	333	398	530	661	793
peel separation, %	25	25	25	25	25	25	25
Extrusion Fillet Seams							
shear strength, N/25 mm	250	350	438	525	701	876	1050
shear elongation at break[2], %	50	50	50	50	50	50	50
peel strength, N/25 mm	170	225	285	340	455	570	680
peel separation, %	25	25	25	25	25	25	25

Note, only performance parameter is weld strength, and peel separation

Welding variables

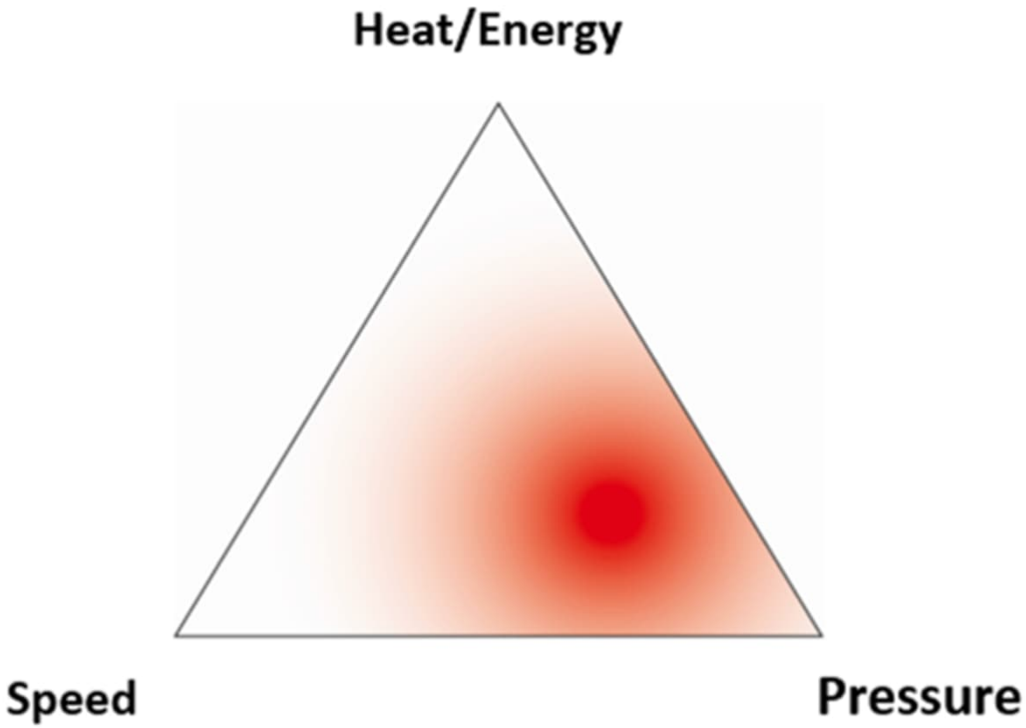


Image from ExcelPlas - https://www.excelplas.com

A successful dual track fusion weld is a combination of:

- wedge temperature
- wedge pressure
- welding machine speed

Increasing the weld temperature, and pressure, to increase the weld speed can make commercial sense, less time spent on site.

This can however result in welds that pass the GRI GM19, but may be doing significant harm to the geomembrane, that will impact its long term performance.

Effect of welding parameters on properties of HDPE geomembrane seams – Zhang, Bouazza, Rowe, Scheirs (2017) Geosynthetics International

- Std-OIT results showed that the outer edge of squeeze-out, or HAZ, was negatively impacted by the thermal welding.
- The peel strength of all specimens was greater than required by GRI GM19

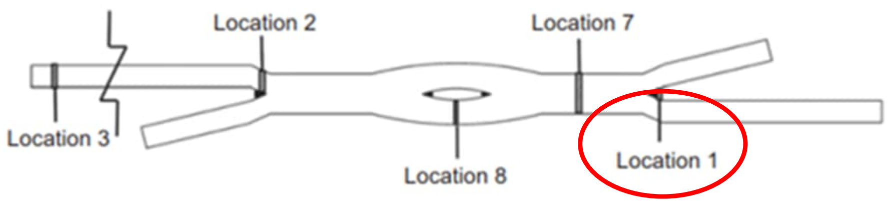


Figure 13. Schematic cross-section view, which shows the sampling locations of the Std-OIT test and the crystallinity test sampling locations of a seam specimen

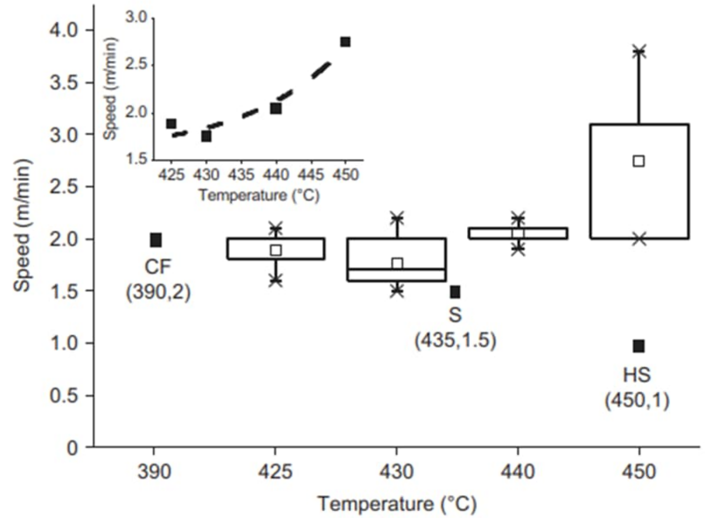
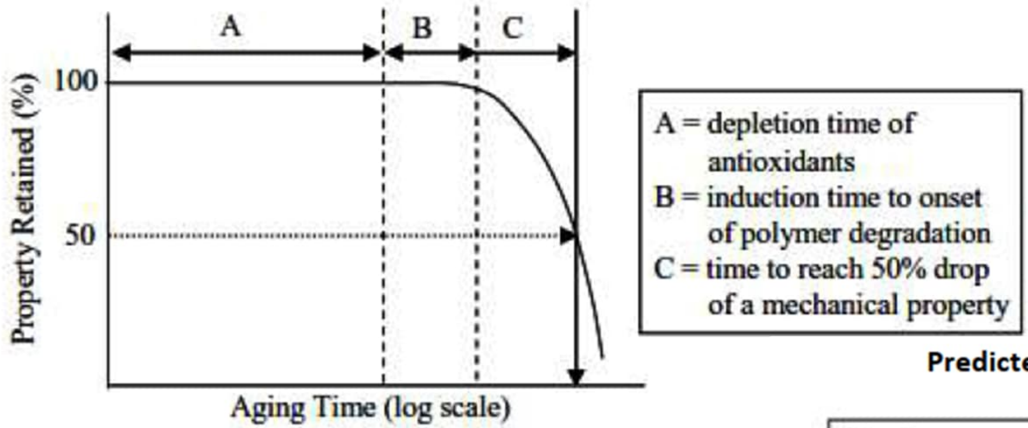


Figure 2. Relationship between welding temperature and speed. Note: the two diagonal crosses are the maximum and minimum values of the set of data. The crossbars at the ends of each whisker are the 95th and 5th percentile. The top and bottom boundaries of each box are the 75th and 25th percentile. The horizontal line inside each box is the median. The little square inside each box is the mean value. The welding temperature and speed of seams HS, S and CF are presented as a solid square in the graph

Why STD –OIT matters

- Stage A – Antioxidant depletion time;
- Stage B – Induction time to the onset of degradation; and
- Stage C – Time to reach 50 % reduction of a specific physical property (i.e., the nominal failure point).

The stages are presented graphically in Figure 3 (Hsuan et al, 2008).



- Reduced Std-OIT will shorten stage A, as there are less antioxidants to deplete, resulting in lower overall geomembrane life in this area

Predicted times to nominal failure for the tested geomembrane (Ewais et al, 2018)

Property	Time nominal failure[a], t_{NF} (years)						
	Temperature (°C)						
	60	50	45	40	35	30	20
Stress crack resistance	54	150	270	470	590	720	1600
Tensile break elongation	54	150	270	470	590	720	1600
Tensile break strength	56	140	230	380	560	660	1200
Very conservative minimum[b]	54	140	230	370	550	640	1100

[a]Predictions are based on the summation of Stage I and II + III.
[b]The calculated from Equation 2 based on the minimum t_{NF} given in Table 3.

Brittle Stress Cracking of HDPE Geomembrane caused by Localized Over-Heating of Fusion Wedge Welds
Marta (2022) GeoANZ#1

- Elevated leakage rate and appearance of "whales" in a geomembrane lined dam after being in service for 4 years

- Whale development process
  - Small 'holes' initiate leakage
  - Geomembrane starts to float
  - Cyclic flexing (i.e. growing and shrinking over time as temperature and water levels change results in tension in geomembrane
  - "Damaged" geomembrane in the HAZ cracks, allowing more water/air in under liner

GEOANZ #2

Brittle Stress Cracking of HDPE Geomembrane caused by Localized Over-Heating of Fusion Wedge Welds – Marta (2022) GeoANZ#1

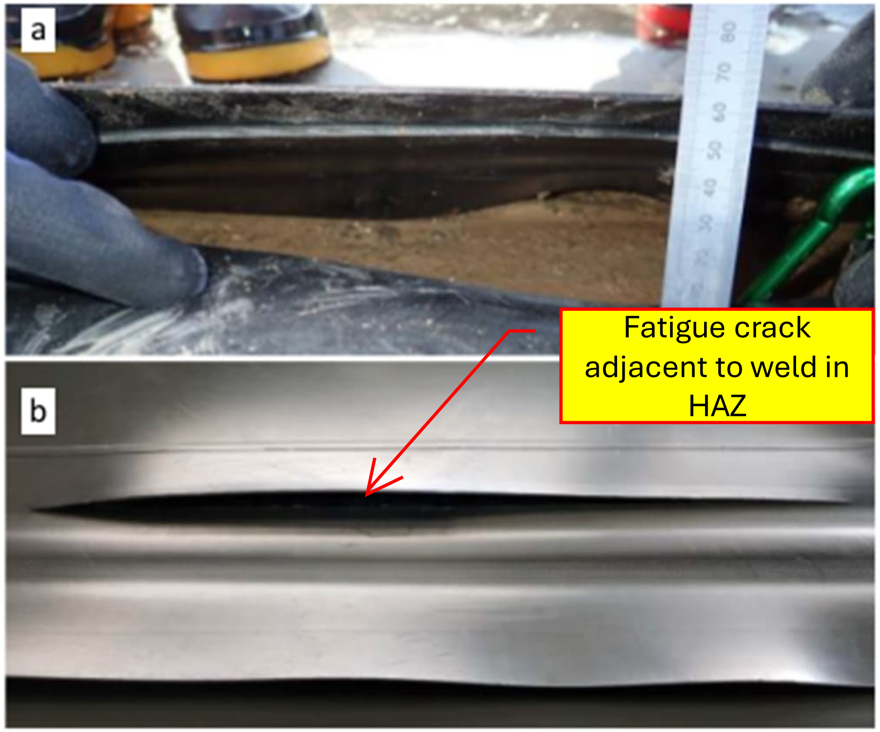


Table 2. Weld profile dimensions.

Dimension (mm)	1(1)	1(2)	1(3)
Thickness of liners	3.93	3.91	3.93
Thickness of seam	3.54	3.49	3.55
Seam reduction thickness	0.39	0.42	0.38
Air channel width	8.72	8.37	8.96
Weld width	11.8	11.8	12.2
Width of squeeze out bead	4.81	4.88	4.98

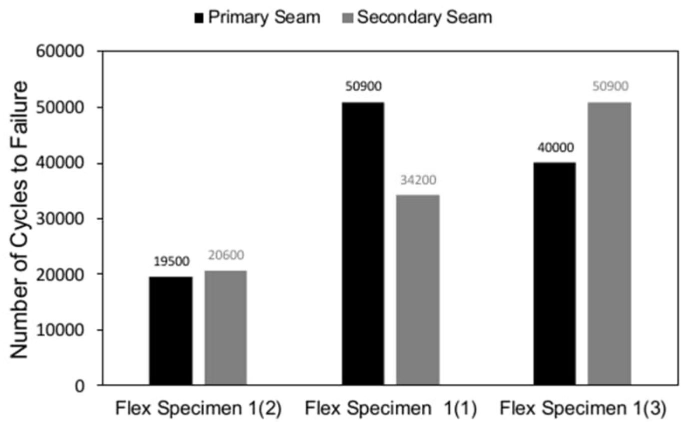
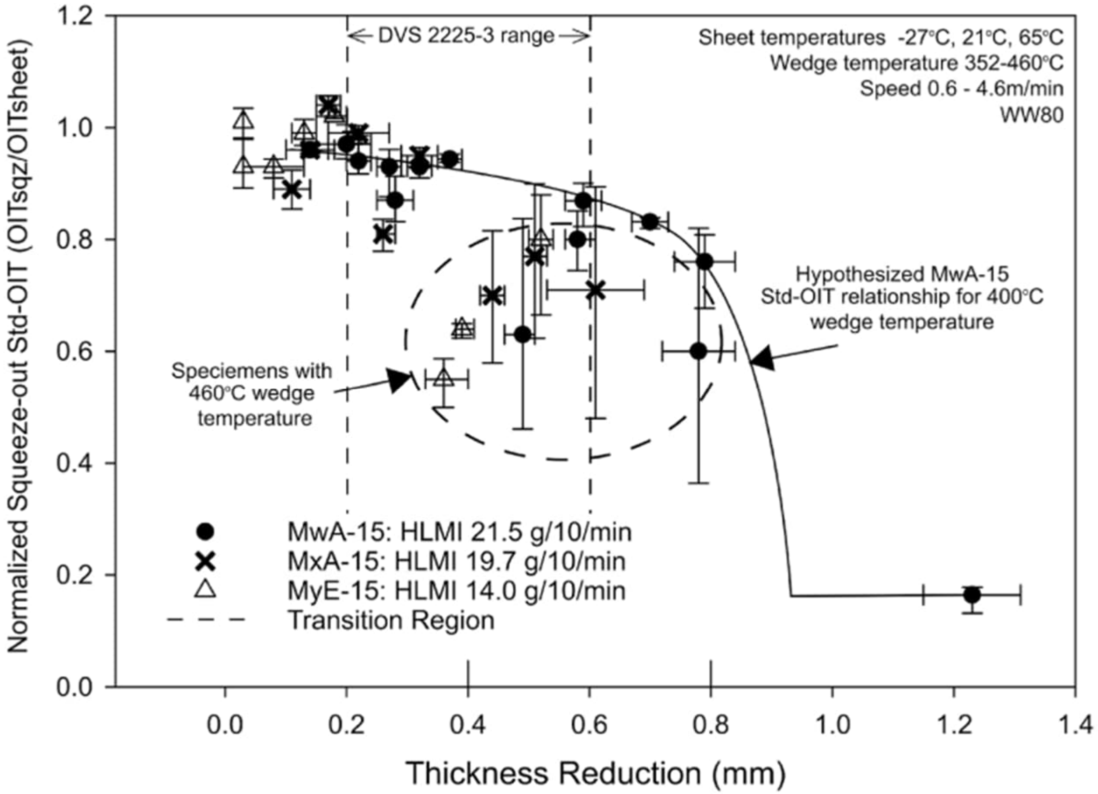


Figure 14. Results of flexural cycle testing

GEOANZ #2

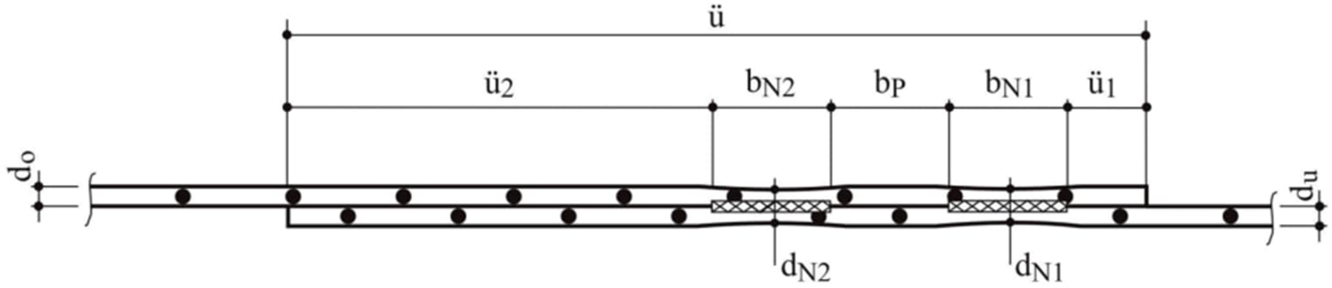
Importance of thickness reduction and squeeze-out Std-OIT loss for HDPE geomembrane fusion seams - Francey W, Rowe K (2023) Geotextiles and Geomembranes

- Seams with thickness reduction exceeding 0.8 mm (high wedge temperature and pressure) found to exhibit greater squeeze-out and Std-OIT loss, with near full Std- OIT depletion for one material
- For the, equipment, and welding parameters examined, adherence to the DVS 2225-3 thickness reduction range, served as a useful criterion for producing seams with the intent of limiting squeeze-out Std-OIT loss



Technical Code DVS 2225-3 : Welding of lining membranes made of polyethylene (PE) for the protection of groundwater October 2019

Lap joint with inspection channel – ÜN



Membrane thickness (d_o, d_u)	≥ 1.5 mm
Front overlap ($ü_1$)	≥ 5 mm < 15 mm
Rear overlap ($ü_2$)	≥ 40 mm
Width of weld sections (b_{N1}, b_{N2})	≥15 mm
Width of inspection channel (b_P)	≥10 mm
Thickness of weld (d_{N1}, d_{N2})	≥ (d_o + d_u) - 0.8 mm (PVC-P or membrane thickness PE 1.5 mm: -0.6 mm) ≤ (d_o + d_u) - 0.2 mm (PVC-P: 0.0 mm; membrane thickness PE ≥ 2.0 mm: 0.4 mm)
Total overlap (ü)	

- Has been used in Germany for over 40 years, key component is overall weld parameter limits
- In the field, the following machine settings (welding parameters) are used:
- Heated wedge temperature 300 to 420 °C
- Specific joining force 30 to 40 N/mm effective roller width
- Speed of travel 0.8 to 2.5 m/min

Way forward

- The IGS Technical Committee Barriers has approached GSI to revise GRI GM19 to include a welded area thickness limit similar to DVS 2225-3. As part of this process international CQA companies and installers were asked for their input. The majority were in support of setting weld thickness parameters for GRI GM19.
- As part of the work of the ASTM D35 committee, a GRI Standard GM36 (11 August 2023) has been developed for HDPE Geomembrane Fusion Seam Thickness Measurement, to allow for a standardised approach to measure the welded area of a dual track fusion seam. This advocates using a thickness gauge similar to those used to measure geomembrane thickness.
- If it is possible to include welded area thickness limits into GRI GM19, then it becomes simpler for consultants or clients to specify this, and to therefore have more control over the welding process and the impact it is having on the parent material.
- In order to manage site work however measurement of the welded area thickness needs to be undertaken, so that during the trial weld stage acceptable machine settings can be determined that fulfil both strength and weld thickness criteria.
- Also new ASTM standard being drafted “Best Practice for the Thermal fusion welding of Geomembranes”

Field measurement during trial welds and site destructive weld testing

Thickness gauge (micrometre)

Vernier calliper

Recent advances/comments

- Eric Blond, Consultant and convener,
- Amir Shahkolahi, Global Synthetics, IGS-TC
- Kerry Rowe, Queens University
- George Koerner, Geosynthetic Institute
- Eddie Weiser, Leister
- Dave McLaury, Consultant
- Todd Harman, Hallaton
- Eric Lamontagne, GE Environmental
- Richard Thiel, Thiel Engineering

Cold weather welding workshop, arranged by Eric Blond, and reported on by Goerge Koerner, held at the GeoAmericas conference in Tornoto, April 2024

“10% thickness reduction may be a good indication of long-term seam quality”

Trial and destructive weld tests from New Zealand installations (2022 to 2024)

Weld thickness tolerance (1.5mm)	(PP1 + PP2)- 0.6	lower limit
	(PP1 + PP2)- 0.2	upper limit
Weld thickness tolerance (2mm)	(PP1 + PP2)- 0.8	lower limit
	(PP1 + PP2)- 0.4	upper limit

ID	Parent piece thickness (1 of 2)	Parent piece thickness (2 of 2)	Weld thickness mm	Weld thickness tolerance mm
D3.1	1.92	1.95	3.15	Pass
D3.1	1.92	1.95	3.25	Pass
D1.1	2.00	2.04	3.11	Failed too thin
D1.1	2.00	1.96	3.39	Pass
D2.2	2.00	2.05	3.06	Failed too thin
D2.2	2.00	1.93	3.33	Pass
D2.1	1.99	1.97	3.41	Pass
D2.1	1.99	1.97	3.07	Failed too thin
D1.3	1.99	2.04	3.11	Failed too thin
D1.3	1.99	2.04	3.10	Failed too thin
D1.2	1.99	2.04	2.85	Failed too thin
D1.2	1.99	2.04	3.07	Failed too thin
D2.3	2.03	1.96	3.42	Pass
D2.3	2.03	1.96	3.07	Failed too thin
D3.1	1.95	1.90	3.50	Failed too thick
D3.1	1.95	1.90	3.17	Pass
Trial Seam 01	1.99	2.00	3.09	Failed too thin
Trial Seam 01	1.94	2.00	3.03	Failed too thin
Trial Seam 02	2.06	1.91	3.03	Failed too thin
Trial Seam 02	2.05	1.90	3.25	Pass
Trial Seam 03	1.95	1.90	3.10	Pass
Trial Seam 03	1.95	1.90	3.23	Pass
Trial Seam 04	1.92	1.93	3.08	Pass
Trial Seam 04	1.92	1.93	3.37	Pass
Trial Seam 05	1.94	1.96	3.06	Failed too thin
Trial Seam 05	1.93	1.90	2.97	Failed too thin

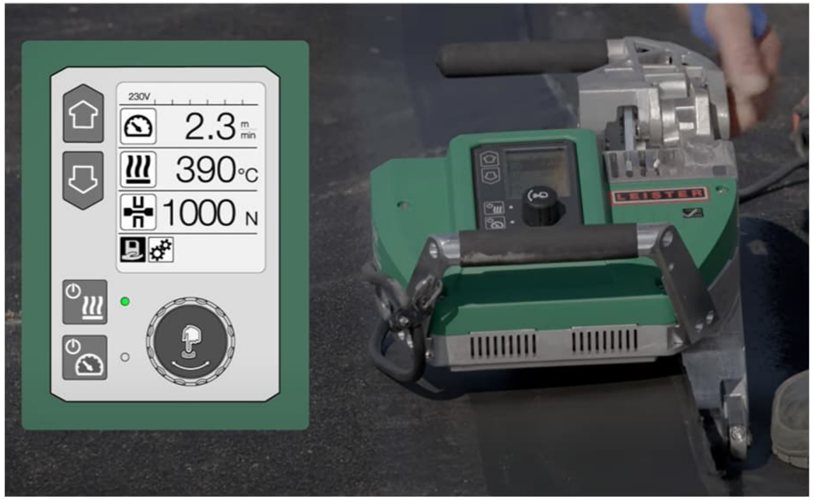
All welds passed GRI GM19 requirements

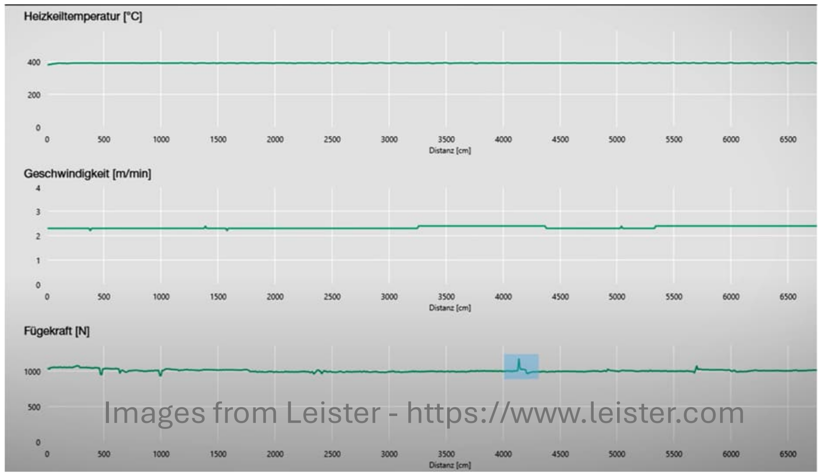
Site	Percentage passing DVS limits	Percentage thickness reduction (target is 10%)
1	46	19.6
2	84	11.6
3	19	19.5
4	50	17.7
5	20	15.8
Avg.	43.8	16.8

The next evolution - data recording on welding equipment

- Recording of weld parameters (speed, temperature and pressure)
- Recording of individual seam lengths, with start and stop time
- Easily identifies and locates weld anomalies via GPS position
- Easily adds seam number, roll number, technician ID etc.
- Data is easily transferable via Wi-Fi

From GeoAmericas workshop:
“The use of smart welders with data aquation (DAQ) systems was recommended. DAQ welders feature displays that show continuous output of key welding parameters(temperature ambient and wedge, pressure and speed). Control, monitor, and record entire welding eco system was identified as critical. Again, slower rates of seaming should be anticipated.”





Images from Leister - https://www.leister.com

Final thoughts

- Welding of geomembranes needs to have more control than just the weld strength
- Limits to weld thickness reduction can be part of the solution, but this still needs to fit into the ecosystem the weld is produced in i.e. weld parameters
- Limited guidance seems to be available from geomembrane manufactures as to what parameters are recommended to limit damage to the geomembrane from the welding process, example from a manufacturer below, similar to DVS 2225-3.

Example for the set-up of the welding machine (target values):

Welding temperature:	300 - 420°C
Pressing force:	30 - 40N/mm roll width
Welding speed:	0.8 - 2.5m/min

- Data recording can assist with monitoring welding conditions as the weld is being made
- It is likely that applying thickness reduction limits will result in installation speed being slowed down. Muller and Wohlecke stated in 2017 (Zero leakage? Landfill liner and capping systems in Germany) that an average installation rate of 1000 m^2/day allows for suitable welding and CQA to be performed that limit impact of welding on the geomembrane. How does this relate to current installation rates?

Thank you

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