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The Separation-In-Plane (SIP) Mode of Failure When Testing Polyolefin Geomembrane Seams

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Overview and Background

The destructive testing of field seamed geomembrane edges* and ends has been an ongoing quality control and quality assurance practice for over thirty-years. The usual procedure is to sample, i.e., physically cut out, sections of the actual production seam from which smaller test specimens are die-cut in the laboratory for testing until failure occurs; see Figure 1a for a number of these samples with test specimens removed. Obviously, this cutting out of the field samples must be suitably repaired with patches as shown in Figure 1b.

(a) Test samples with destructive test specimens removed

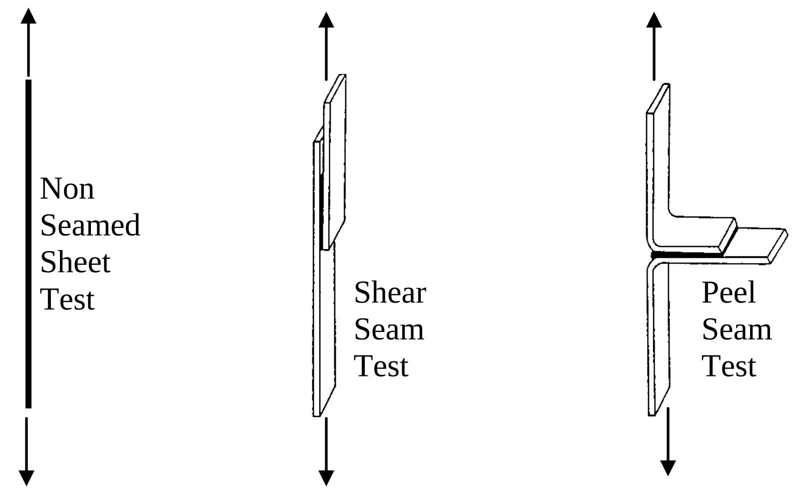
(b) Repair patch placed over previously cutout destructive seam location

Figure 1 – Geomembrane field seam samples and repair.

The test specimens are typically 25 mm (1.0 in.) wide and tension tested in a constant-rate-of-extension testing machine in both shear and peel modes. These two seam test modes are shown in Figure 2, in contrast to the sheet test, along with the appropriate ASTM standards for various types of commonly used geomembranes. The seam strength values are usually compared to the

*This White Paper does not apply to PVC or EPDM geomembranes only to the polyolefins HDPE, LLDPE and fPP.

sheet itself or compared to a specification which must be agreed upon by the parties involved. In this regard see the GRI-GM19 seam strength specification which is often cited and used accordingly (www.geosynthetic-institute.org/specs.htm).



Type	Sheet	Shear	Peel
HDPE LLDPE	D 6693 D 6693	D 6392 D 6392	D 6392 D 6392
fPP	D 882	D 3083 or D 6392	D413
fPP-R PE-R LLDPE-R CSPE-R	D 751	D 751	D 413

Figure 2 – Sketches of geomembrane sheet and seam testing and the relevant ASTM test methods.

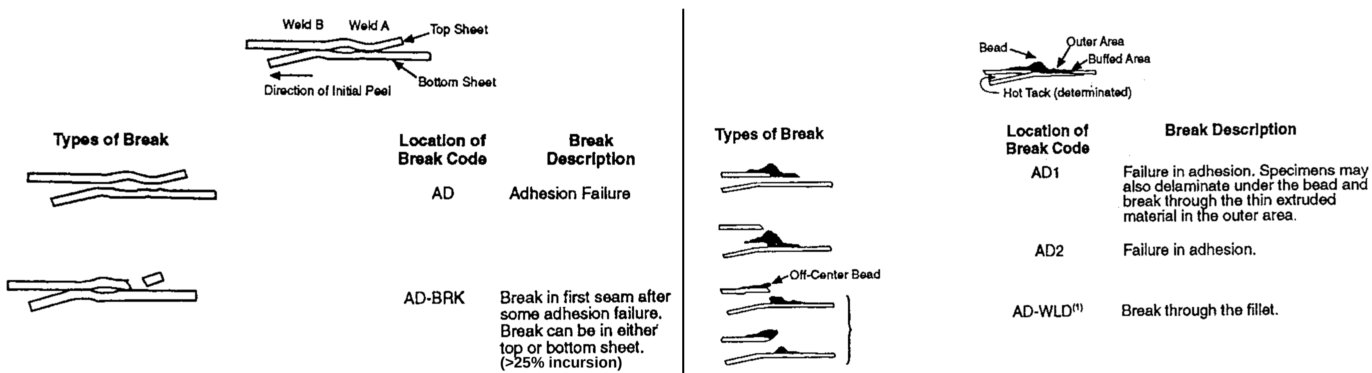
In general, there are three criteria which must be met by the seams being evaluated, see Table 1. This particular White Paper focused entirely on the actual "type of break" of the tested seam.

Table 1 – Seam acceptance criteria

Item	Shear Test	Peel Test
strength	meet or exceed spec	meet or exceed spec
additional requirement	minimum elongation	maximum incursion
type of break	in sheet, not seam	in sheet, not seam

Locus-of-Break Patterns (or Codes)

There are many possible patterns for shear and peel tests to eventually break (aka, pull apart) in a tension testing device. In the early 1980's Metrecon (Haxo, 1988) proposed numerous acceptable and nonacceptable patterns. In general, his thoughts were to require eventual failure to be within the sheet material on one side or the other of the physical seam itself. Conversely, if the seam pulled apart within itself it was then an unacceptable pattern indicating a seam test failure. Unacceptable failure modes according to ASTM D6392 are shown in Figure 3. These are all examples of non-film tear breaks, or "non-FTB".



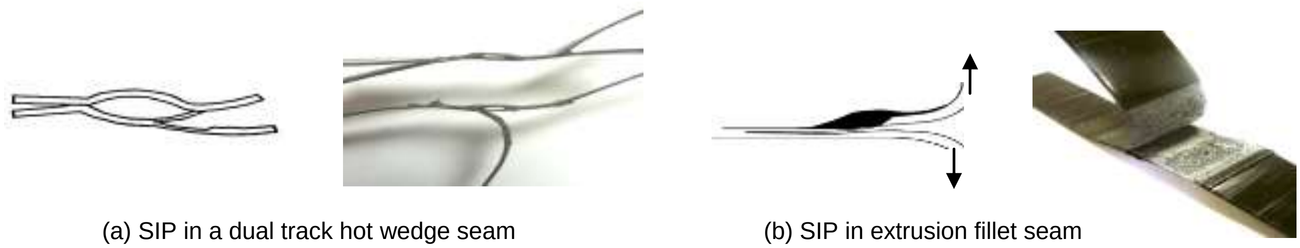
(a) Unacceptable Hot Wedge Weld Breaks (b) Unacceptable Extrusion Fillet Welds

Figure 3 – Unacceptable (non-FTB) seam failure models per ASTM D6392.

The Separation-in-Plane (SIP) Failure Mode

Historically, scrim (or fabric) reinforced geomembranes (fPP-R, PE-R, LLDPE-R and CSPE-R) which are fabricated using discrete layers of material fail when tested in peel along one or the other fabric interfaces within the composite sheet. By virtue of the manufacturing process this can be expected. As long as the specified strength is achieved it can be considered as an acceptable failure pattern. Beginning in about 2000, however, this type of failure began to occur within homogeneous sheets, i.e., within non-scrim reinforced geomembranes. Called separation-in-plane (or SIP) it was very disconcerting to the laboratory technician and to others as well.

SIP generally (but not always) occurred in peel testing and can travel within the upper or lower sheet a considerable distance, e.g., up to 100 mm (4.0 in.). It often travels near midplane of the sheet thickness with no visual fibrils between the opposing surfaces but has also occurred as a very thin "skin" which can only be measured using a micrometer. It has occurred in both hot wedge and extrusion fillet seams, as shown in Figure 4.



(a) SIP in a dual track hot wedge seam with splitting of the lower sheet

(b) SIP in extrusion fillet seam which occurred during peel testing

Figure 4 – Occurrence of SIP during peel seam testing.

A literature review of experts commenting on the SIP phenomenon is presented in Table 2. Here it is seen that the only common characteristics among the four commenters is that SIP is more prevalent in thicker geomembranes than in thinner ones; but recently it has occurred in 1.0 mm thick sheet. Perhaps more disconcerting is that the suggested causes vary considerably among those writing on the subject. Even the conclusions offered in Table 2 offer little as to corrective action recommendations going forward.

Of the above possible causes, a plausible one to the writers is that SIP may be caused by a change (unknown to us) in the master batch carrying the carbon black and antioxidant additives into the extruder for homogenization with the resin. In this regard, the carrier resin of master batches is sometimes lower in density (or even different) than the base resin of the geomembrane. Planes of weakness may (?) result by inadequate mixing and nonhomogenization leading to the phenomenon. Note that this possible cause was also suggested by both Allen and Struve. However, to our knowledge it was never conclusively proven to be the case.

Table 2 – Literature comments on separation-in-plane (SIP)

Reference	Date	Observed Occurrences	Cause(s)	Conclusion
Smith in Mining Record	July/Aug. 2001	HDPE ≥ 1.5 mm (not LLDPE)	1. rapid cooling 2. high plant temp 3. improper mixing 4. all of above	1. OK if above spec values 2. long-term concerns 3. no consensus
Nobert in Poly-Flex Newsletter	Aug. 2001	1. HDPE ≥ 1.5 mm (not LLDPE) 2. mainly blown film 3. fast testing rates 4. mainly XMD	1. rapid cooling (skin-core effect)	1. artifact of rapid testing 2. not a material defect 3. not a seam defect
Allen in Smith memo	Aug. 2001	n/c	1. poor carbon black dispersion 2. improper mixing	n/c
Struve in GFR	March 2003	1. all GM types 2. thicker GMs 3. blown film mainly	1. certain master batches 2. contaminants 3. temp. gradients 4. cooling conditions 5. rapid testing rates	1. low density carrier resin in master batch 2. resins with excessive low density “tails”

<u>GSI Recommendations Regarding “SIP”</u>

At GSI we had many inquiries regarding SIP from about 2000 to 2005 when they abruptly stopped occurring. Without specifically discovering the cause of the issue, SIP then became a moot point. More recently, however, several cases of SIP have reappeared and we at GSI have been asked to state our position on the issue, hence this White Paper at this time.

GSI presently feels that destructive seam test specimens failing in a separation-in-plane (or SIP) mode are acceptable *under the provision that all other criteria are met or exceeded, recall Table 1.* In accordance with this statement, our seam specification, GRI-GM19, has been amended. While this position is less than satisfying (since the root cause of the failure mechanism has not been conclusively proven), the seams must eventually fail and if it occurs within the sheet rather than perpendicular to it, the seam should not be rejected.

References

Allen, S. (2001), see Smith.

ASTM D413, "Standard Test Methods for Rubber Property – Adhesion to Flexible Substrate".

ASTM D751, "Standard Test Methods for Coated Fabrics".

ASTM D882, "Standard Test Method for Tensile Properties of Thin Plastic Sheeting".

ASTM D3083, "Specification for Flexible Polyvinyl Chloride Plastic Sheeting for Pond, Canal, and Reservoir Lining".

ASTM D6392, "Standard Test Method for Determining the Integrity of Nonreinforced Geomembrane Seams Produced by Thermo Fusion Methods".

ASTM D6693, "Standard Test Method for Determining Tensile Properties of Nonreinforced Polyethylene and Nonreinforced Polypropylene Geomembranes".

GRI-GM19 (2001), "Standard Specification for Seam Strength and Related Properties of Thermally Bonded Polyolefin Geomembranes".

Haxo, H. (1988), Lining of Waste Containment and Other Impoundment Facilities, U. S. Environmental Protection Agency, EP/600/2-88/052, September ~ 1000 pgs.

Nobert, J. (2001), "Discussion on Separation-in-Plane," Poly-Flex Newsletter, PolyAmerica Corp., Fort Worth, TX, August.

Smith, M. (2001), "Comments on Geomembrane Seam Testing," Mining Record Magazine, July/August.

Struve, F. (2003), "Separation In Plane (SIP)," GFR Magazine, Vol. 21, No. 2, March, pp. 24-25.