Seams in HDPE Geomembranes: The Quality Target

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ABSTRACT: Sets of quantitative and qualitative criteria that define "good" fusion and extrusion seams in HDPE geomembrane are presented as a common target for those developing seaming equipment and technology, and those developing nondestructive methods of seam evaluation. The criteria include seam peel and shear properties, impact resistance, and adjacent geomembrane stress rupture resistance. Qualitative criteria include microstructural observations of thin-slice microsections by transmitted light microscopy.

1 INTRODUCTION

At a United States Environmental Protection Agency smart welding workshop in 1993 it was clear that, among participants, there was no consistent view of what constituted a "good" seam in HDPE geomembrane. Some thought no improvements on existing seams could be made, others thought, and appeared to show, that significant improvements could be made. This situation exists, in large degree, because there are no well-defined criteria or specifications for a "good" seam - a seam that not only is leaktight at the time of installation, but one that will remain leaktight during its projected lifetime.

2 THE CONCERN

Rarely do engineering structures fail because components simply wear out; they fail because a component contains an unexpected flaw that is introduced, or gradually develops, within the component, and becomes of a critical size that causes rapid unexpected failure. It is, therefore, necessary to define such critical flaws (defects) in order to determine whether a component will perform as intended, or should be rejected or repaired. The adequacy of each component must therefore be described in terms of its properties, characteristics, internal features, sizes of flaws (not all flaws are unacceptable), as to whether it is acceptable for service. A seam in an HDPE geomembrane is no different.

There is a minimum, but unique, set of criteria that describe an optimum seam, that will change as the knowledge base grows. Such a set of criteria will provide a common target for all seaming techniques and will define the criteria upon which destructive and nondestructive testing parameters are based. NDT technology is on the verge of being able to define features other than simply holes in a geomembrane (Peggs et al., 1994), necessitating decisions on whether such features are, or are not, critical. It is essential that those criteria that define a successfully welded seam are similar to, if not the same as, those that can be monitored by NDT methods. If there is no such common target, there will be a large void in the knowledge base that can only result in unexpected field failures.

3 EXISTING CRITERIA

Seams are presently generally evaluated in the field by subjecting them to destructive peel and shear tests which measure a shear strength, perhaps a peel strength, and location and nature of the break (NSF, 1993). These criteria only determine the characteristics of the seam at the time of testing - they present no information on the potential durability of the seam and adjacent sheet. In addition the peel test does not evaluate the bond strength of the full width of the seam if the edge that is tested first is satisfactorily bonded. Ransom (1993) has developed an incremental peel test that is performed along the length of the seam, but, in areas of adequate bonding, it requires the operator to manually cut the bond to assess the next increment of length. This method does provide some useful information about bond strength across the full width of the seam, but the need to manually assist the propagation of peeling introduces the possibility of diverting the separation plane away from its natural vector. It has been shown (Rollin et al., 1989, Struve, 1993) that seam quality is significantly influenced by welding speed, welding temperature, surface condition, and applied pressure. These parameters may also significantly affect the long term behavior of the adjacent geomembrane. Thus, seam assessment criteria must include parameters for the adjacent geomembrane.

Except for those seams that have not been adequately bonded during seaming, the only failure process that the authors are aware of, in the field, is stress cracking within and adjacent to the seam. Such cracking is initiated at regions of residual stress, geometrical notches, overheating, and crazing. Notches, such as those caused by grinding or overheating, influence the ductility of the adjacent geomembrane. Crazes, the precursors of stress cracks, are introduced in bonded surfaces that peel apart. Hence, Peggs and Little (1985) have proposed that shear elongation and peel separation are two parameters that should be measured to provide information on the probable durability of a seam.

Internal and, particularly, surface defects are the initiating sites of stress cracks. Such defects are not often reflected in the measurement of bulk material properties. However, such features do influence impact loading properties. Rollin (1993) has proposed that a falling tup impact test be performed on both parent geomembrane, and geomembrane adjacent to a seam to determine if the seaming process has unduly affected the durability and performance of the geomembrane. Both shear elongation and impact testing may also identify microstructural orientation boundaries between as-extruded and melted/solidified material at the edges of seams proposed by Peggs and Carlson (1990) to be an initiating site for stress cracking.

It is important that as much information as possible concerning the future performance characteristics of the seam be generated from destructive tests.

None of the conventionally performed nondestructive tests provide information on any seam feature other than a completely penetrating hole. Only pulse-echo and shadow ultrasonics (Peggs et al., 1985) will identify lack of bonding, voids, or interface contamination within a seam, but these techniques are impractically slow and difficult to perform in the field. Infrared thermography (IRT), presently in the feasibility study phase, will identify internal defects and shows potential for broadly classifying seam bond strength (Peggs et al., 1994). Therefore, NDT methods will soon be developed to the stage that they can define and quantify internal seam features, thus requiring a decision as to whether such features are critical flaws.

It is desirable, therefore, that the criteria that determine whether a seam has been successfully seamed include those that are of a kind that can be defined by nondestructive testing.

4 PROPOSED "GOOD" SEAM CRITERIA

It is important to note that the proposed criteria that follow are not those that should be used verbatim in geomembrane liner specifications. Rather, they are a set of criteria, based on state-of-practice research knowledge, that can be used as a common target of state-of-the-art research and development projects. As research progresses and knowledge improves, these criteria should be adjusted accordingly. Nevertheless, some of the criteria will form the basis of state-of-practice liner project specifications; parameters that could be used on a production basis are identified in section 6.

Two types of criteria are presented - quantitative mechanical test data, and qualitative microstructural observations. Impact test (Rollin, 1991) and seam peel and shear test (Peggs et al., 1985) methods are described in the references. Seam elongation is defined (Figure 1) as the grip displacement (ΔL) expressed as a function of the specimen distance (L) between the edge of the seam and the nearer grip bounding the section of the specimen in which failure occurs. In the impact test; the center of the tup is positioned to impact the seam specimen in the center of the seam. The

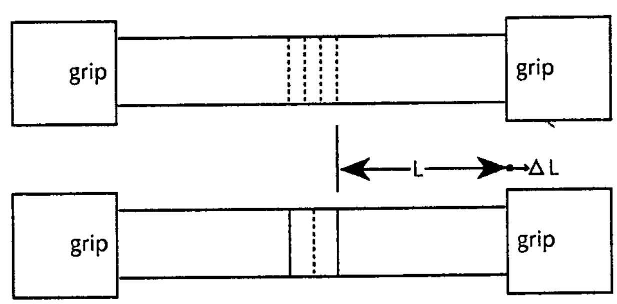

Figure 1. Parameters used for shear elongation. Fusion seam (top), extrusion seam (bottom).

impact energy (tup weight x height) at the transition from ductile to brittle breaks is determined. Stereo light microscopy (or scanning electron microscopy) is used to determine the morphology of the break.

The microstructural observations can be made by microtoming a thin slice (10 - 20 μm) microsection and examining it by transmitted light microscopy using crossed polarizing filters (Peggs et al., 1989). The filters more clearly identify the heat affected zone (HAZ) of the seam and show the locations of residual stresses. In the absence of a microtome, some information (unbonded areas, microcracks, inclusions) can be obtained by examining smoothly cut cross-sections of seams using reflected light microscopy (Rollin 1991).

4.1 Thermal fusion seams:

4.1.1 Quantitative criteria:

- Shear stress: >95% geomembrane specified yield stress (GSYS)
- Shear elongation: >500%
- Peel stress: >80% GSYS, for both edges of both tracks
- Peel separation: zero
- Impact resistance: 45 J/mm thickness
- Stress rupture: T_t geomembrane (ASTM D5397) >250 hr. Seam rupture time at 80°C >80% of geomembrane at 80°C (unnotched specimens)

4.1.2 Qualitative microstructural criteria:

- No voids, inclusions, dirt, foreign materials, or interface layers within the weld zone when viewed under normal transmitted light.
- Symmetrical, homogeneous squeeze-out beads. The sides of the squeeze-out bead shall be in full contact with the adjacent geomembrane surfaces. No residual stress or crazes (unopened cracks) at the roots of squeeze-out beads, when viewed under polarized light.

The GSYS is typically the population mean yield strength less two standard deviations.

4.2 Extrusion seams:

4.2.1 Quantitative criteria:

- Shear stress: > 95% GSYS
- Shear elongation: >500%
- Peel stress: >70% GSYS
- Peel separation: zero
- Impact resistance: 45 J/mm thickness
- Stress rupture: T_t geomembrane (ASTM D5397) >250 hr. Seam rupture time at 80°C >80% of geomembrane at 80°C (unnotched specimens)

4.2.2 Qualitative microstructural criteria:

- No voids, inclusions, or interface layers in weld zone when viewed under normal transmitted light.
- Included angle less than 60° (no undercutting) at edges of extruded bead. This implies no excess resin bordering main body of extruded bead.
- No residual stress or crazing at the triple point (bottom corner at edge of top geomembrane, where both geomembranes and the extrudate contact each other) when viewed under polarized light.
- No crazes in the top surface of the bottom geomembrane at the edge of the extruded bead.

5 DISCUSSION

The proposed criteria apply to smooth geomembrane and partially to friction enhanced geomembrane. However, due to the many differences in texturing and structuring processes, it is not possible to provide generic quantitative "good" seam criteria for friction enhanced geomembranes, except to require that seam properties be comparable to the geomembrane material in its form adjacent to the geomembrane. Thus, if a textured geomembrane has a smooth strip where the seam is made, the properties of the smooth strip are the reference values. However, if an end-roll seam is made in textured material without removing the texture, the properties of the textured material are referenced. For textures that are thermally bonded to the geomembrane after the primary extrusion process, this will mean significantly different reference stress rupture values at edge-of-roll (smooth) and end-of-roll (textured) seams.

The stress rupture resistance of the seam is assessed as follows. The basic smooth geomembrane is tested according to ASTM D5397 to ensure it has a ductile/brittle transition time exceeding 250 hr. An unnotched specimen of the smooth geomembrane is then tested (Thomas and Woods-De Schepper, 1993) at 80°C, in Igepal, at a constant load equivalent to 25% of the room temperature yield stress of the geomembrane. The time to break is determined, ensuring that the specimen fails in a quasi-brittle manner: i.e. with no macro-ductility. It should be noted here that the HDPE does not actually become brittle, it simply fails in an apparently brittle manner.

The seam sample is then tested, without a notch, under the same conditions as the geomembrane specimen, at 80°C. A notch cannot be placed in the specimen since changes that have occurred on, or close to, the surface of the material are being identified. It is also important to note that the seam specimen should be tensioned between the lower geomembrane at the seam and the free flap of the lower geomembrane underneath the seam; not from geomembrane to geomembrane across the seam, since the influence of seaming on the performance of the geomembrane adjacent to the seam is being assessed. The seam must not be subjected to additional bending stresses as would otherwise occur.

6 PRODUCTION SEAM SPECIFICATIONS

It is recommended that production seam specifications be based on the quantitative "good" seam criteria only, and not to exceed the following without consultation with, and the approval of, the installer:

- Shear stress: >90% GSYS
- Shear elongation: >100%
- Peel stress: >60% GSYS extrusion seams
  >70% GSYS fusion seams
- Peel separation: <10% originally bonded area
  excluding squeeze-out bead

The stress rupture and impact resistance data are not yet developed to the point where they can be universally and routinely applied.

7 SUMMARY

These "good" HDPE geomembrane seam criteria are presented for adoption as international reference criteria for the development of all technologies associated with seam fabrication and testing. Such criteria are necessary because existing criteria do not provide any information on the potential durability of seams, and because there are no common parameters for seam fabrication and nondestructive testing technologies. Both technologies will soon require the common definition of critical defect sizes.

These "good" seam criteria should not be used verbatim for conventional production seaming specifications.

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