Geomembranes and Seams

Ian D. Peggs
I-CORP INTERNATIONAL, Inc., USA
icorp@geosynthetic.com

ABSTRACT: Geomembranes and their seams have been destructively tested the same way for many years. However, it is still not appreciated that only shear elongation and peel separation provide useful information on weld integrity. It would be desirable to preclude seam destructive testing and to replace it with nondestructive testing (NDT) methods. Electrical methods are now available for locating leaks anywhere in liners whether covered or exposed. On landfill caps infrared spectroscopy can locate leaks much faster. Unfortunately, these methods will not assess the bond efficiency of a weld. However, ultrasonic (UT) methods, both pulse-echo and pitch-catch techniques are being developed to evaluate bond quality and the presence of internal flaws that may become leaks in service. The most promising method for the NDT evaluation of seam bond strength is infrared thermography (IRT) that even appears capable of identifying variations in weld zone microstructure due to cycling of the welder wedge temperature.

1 INTRODUCTION

Geomembrane seams have been nondestructively and destructively tested the same way for many years. Only the acceptance criteria for destructively tested samples have been updated, but not far enough. However, seams are only a very small fraction of the total area of the liner which, until the development of electrical methods, could only be monitored visually

It is past time that these test methods were reviewed and updated to take advantage of new technologies and the statistics generated over many years of testing. If this is not done we are wasting much time and are not achieving the highest quality lining systems.
The International Association of Geosynthetic Installers (IAGI, 2004) has recently published a white paper that presents alternative methods of testing seams and complete liners and the compromises that can justifiably be made in destructive testing if more updated methods of assessing liner quality are used

2 SEAM DESTRUCTIVE TESTING

Since the beginning of the industry seams have been tested and assessed on the basis of shear strength and peel strength. Many liner specifications still require only these two parameters. However, Peggs (1996) has shown that these two parameters provide no practically useful information on the efficiency of bonding. Consider that whatever the thickness of the geomembranes being welded the actual weld interface area is the same and the expectations of weld strength should be the same. Yet, when we specify shear and peel strengths the specified strengths increase with thickness. Does this mean we are expecting better bonding in thicker geomembranes? If we are welding the same materials with the same interface area we should be achieving the same weld properties independent of thickness. In specifying higher strengths for thicker materials we are simply measuring the strengths of the geomembrane itself. In no way are we assessing the weld integrity to any significant extent.

2.1 *Seam Shear Tests*

Consider that the breaking load of the geomembrane is a function of the cross sectional area of the seam specimen, typically 25 mm wide by, for example, 2.5 mm in thickness, or 62.5 mm^2. Therefore, with a yield strength of 14 MPa the geomembrane will yield at a load of 35 kN/m.

On the other hand the two tracks of a hot wedge seam, each 10 mm wide, have a total bonded area of 500 mm^2. Since the shear strength of a material is approximately 50% of the tensile strength (7MPa) the weld has a theoretical shear strength of 140 kN/m.

In other words the strength of the weld is only 25% of the target shear strength of parent geomembrane material. For 1 mm thick geomembrane the value is 8%. Therefore, when tested in shear, the geomembrane fails at the edge of the weld before the weld has not even been challenged to 10 - 30% of its desired strength. If the weld bond is less than 10 – 30% efficient it will separate when the specimen is being inserted into the tensile machine. Similar considerations apply to the measurement of peel strength (Peggs, 1996). Thus, specified shear and peel forces increase with thickness simply because the thicker geomembranes can tolerate higher loads before breaking. Consequently, welds in thicker geomembranes are tested to higher levels than those in thinner geomembranes, but even at the higher thickness the weld is not challenged to significant levels. Thus, there is no practical need to measure strength parameters.

In the seam shear test the only practical parameter to measure is the ductility of the adjacent geomembrane, to ensure that any mechanical preparation required and the thermal energy input during welding have not embrittled the geomembrane. In HDPE, grinding gouges parallel to the weld and overheating during welding can affect the long-term mechanical durability of the liner. It is suggested that an elongation of 200% of the distance between the edge of the weld and the adjacent grip (the gauge length) be specified as the minimum elongation for smooth and structured profile sheet, while 50% be used for randomly textured sheet. Since one geomembrane will be thinner than the other, break will occur in the thinner so the gauge length should not be the total distance between grips.

2.2 *Seam Peel Test*

The important parameter in the seam peel test, particularly in HDPE seams, is the amount of peel separation, expressed as either a proportion of the originally bonded area or of the width of the weld, exclusive of the squeeze-out bead. The ASTM D6392 test method requires a measurement of the distance of maximum peel incursion and the GRI.GM19 seam specification uses and area measurement of peel separation, but there is presently some consideration of changing to area in the ASTM test method. GRI.GM19 specifies a maximum of 25% of area separation as being acceptable but experience and caution show that zero is easily feasible and technically desirable for HDPE.

Figure 1 shows the cross section of an HDPE weld that has been separated. One of the separated surfaces contains a large amount of crazing, the precursor of stress cracks. When this peeled sample was subjected to a stress cracking test it was found that the time to break had been reduced to about 30% that of the basic sheet. While it is often claimed that peel stresses do not occur on a liner in service, this is not correct. There are many instances, such as at wrinkles, at pipe boots, and at corners, where peel stresses can be induced in seams. Therefore, unless it is known that a specific HDPE geomembrane is made from a resin with very high stress cracking resistance it is as well to specify that no peel separation will be allowed in the seam peel test.

Figure 1. Crazing in peel-separated weld. Microsection viewed with crossed polarizing filters.

Therefore to assure maximum durability HDPE seam peel specifications should be as follows:

Shear elongation for smooth and structured geomembrane	>200%
Shear elongation for random textured geomembrane	>50%
Peel separation	zero

2.3 ***Separation-in-plane***

In some cases, particularly with polypropylene (PP), and to a lesser extent (but apparently increasing) with HDPE, an apparent delamination of the geomembrane can occur, in which the weld interface does not separate, but in which initial break starts into the geomembrane then transforms into a delamination within the plane of the geomembrane itself. Thus, one side of the separated specimen will be thicker than the other and the central air channel is retained intact, as shown in Figure 2.   This phenomenon is called separation-in-plane (SIP).

Figure 2. SIP delamination in the geomembrane during peeling

Within GRI.GM19 it is an acceptable mode of failure provided the force of separation exceeds the specified peel strength.   However, as noted above, this does not, per se, signify an adequately high strength between layers in the geomembrane. If peeling or delamination can occur the interface bond strength is quite low. In some extreme cases (Peggs 1985) and as shown in Figure 3 the microstructure contains white streaks along which the geomembrane can be separated quite easily by hand.

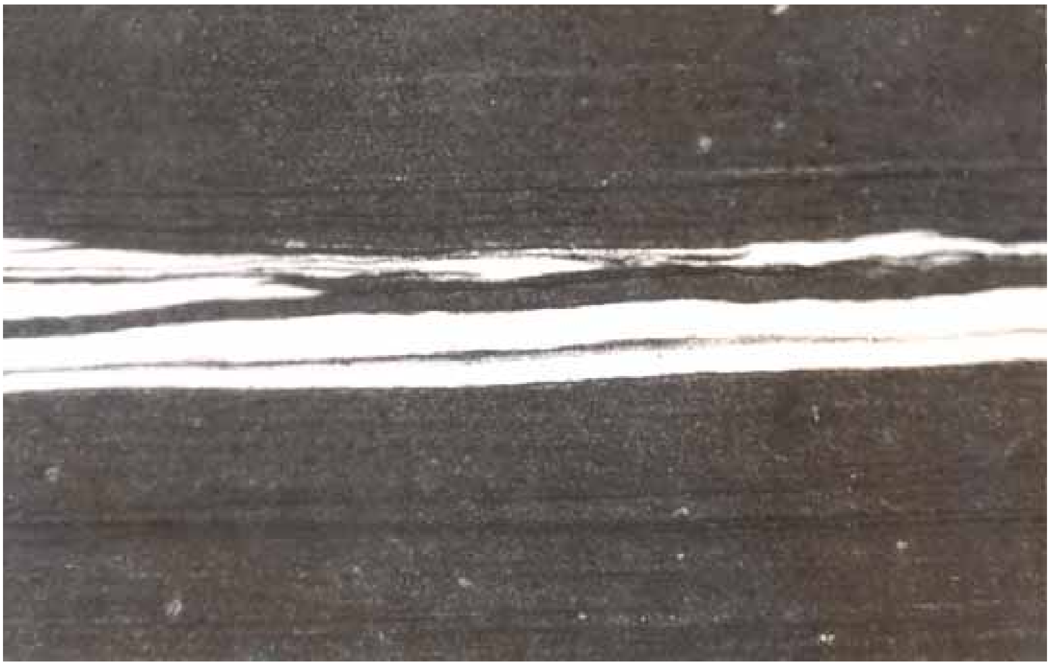

Figure 3. Microsection of geomembrane that separated along the white streak.

While there have been a number of proposals for the occurrence of SIP (Struve 2003), such as incompatible carrier resins for additives, highly-loaded additive masterbatches, internal shearing, and differential contraction due to thermal gradients during processing, there is no widespread agreement or experimental confirmation of its cause. Until we fully understand its cause it appears unwise to accept extensive SIP. A compromise approach, until we better understand the phenomenon, would be to accept SIP provided it progressed no further than 65% across the width of the weld track with final break occurring to the outside of the seam before reaching the center air channel. Requiring a minimum peel strength to justify SIP still has no practical value as previously noted.

3 SEAM

Seams are typically tested by center air channel pressure testing (ASTM D5820), vacuum box testing (ASTM D5641), or spark testing (ASTM D6365). As presently performed all of these tests simply assess the continuity of the seam. They do not assess seam bond strength. However, Thomas and Stark (2003) have recently proposed for PVC geomembranes that the air pressure test can be used as a continuous peel test to assess long lengths of seams. It seems feasible to apply such techniques to other geomembrane materials as well. Conventional air channel and vacuum box testing are well-established procedures and require no direct calibration. However, since no signal in a spark test is an indicator of an acceptable extruded seam it is necessary that calibration be performed. It rarely is, and when it is it is based on geomembrane thickness which may not be appropriate.

3.1 *Spark testing*

There are many reasons, other than a good seam, why spark testing will give no signal – the voltage may not be high enough, the circuit may not be complete, the electrode can be held off the surface, etc. The voltage must be set to jump the length of the expected leakage path, which may be anything from a pinhole directly through the geomembrane itself (the thickness of the geomembrane) to a wandering hole from the edge of the extruded weld bead on the top sheet along the weld interface to the edge of the top sheet, perhaps a distance of 10 mm. The voltage should be set according to the following equation in ASTM D6365:

$$V \text{ (volts)} = 7900 \sqrt{\text{distance (mm)}} \qquad (1)$$

An artificial hole should be placed in a trial weld to ensure that the set voltage will detect that type of leak passageway.

Note that if a spark test is done on a newly installed liner of a concrete basin it might find a number of holes in the welds that will be repaired. The basin when filled with water will probably be found to leak. When emptied, to locate the leaks, a new spark test may find these additional holes in the welds. The project engineer may claim that the spark survey was improperly performed the first time since it apparently failed to find leaks. While these "new" holes will probably have been present during the first survey they may have been too long for the spark to discharge through the air in the passage, but now the passage is filled with moisture it will be more conductive and allow a spark discharge. Therefore, this behavior does not indicate that the spark test was incorrectly performed the first time; it indicates that one needs to recognize the boundary conditions of the test procedure. It is also possible that new holes were generated as the liner was filled and stressed for the first time.

3.2 *Ultrasonic methods*

In the 1980s Schlegel Lining Technology implemented the ultrasonic pulse-echo method for defining weld integrity. Identical to thickness measurement in the metal pipe and tank industries it required the flat end of a transducer to be coupled to the surface of the weld with water or a sound conducting grease. An ultrasound signal was sent from the top surface of the weld to the bottom and the time for this signal to be reflected from interfaces indicated the integrity of the weld. Naturally, only one reflection was expected from the opposite surface of the weld – intermediate signals indicated a lack of bond at the weld interface. The method was discontinued due to the rough surfaces of weld, particularly fillet extrusion welds that were the most likely to contain voids and discontinuities. Their varying thickness was also a problem. As ultrasonic technology developed, wheeled transducers allowed the interrogation of every millimeter of weld using the pitch-catch method that input the sound into the geomembrane on one side of the weld (Figure 4) and picked up the signal in the geomembrane on the other side of the weld (Peggs et al., 1985). The change in profile of the sound pulse (Figure 5) reflected the quality of the weld interface. This technique was developed into standard GRI.GM1. However, results are somewhat more varied in the field due to varying contact pressures as the wheels traverse wrinkles and waves in the liner.

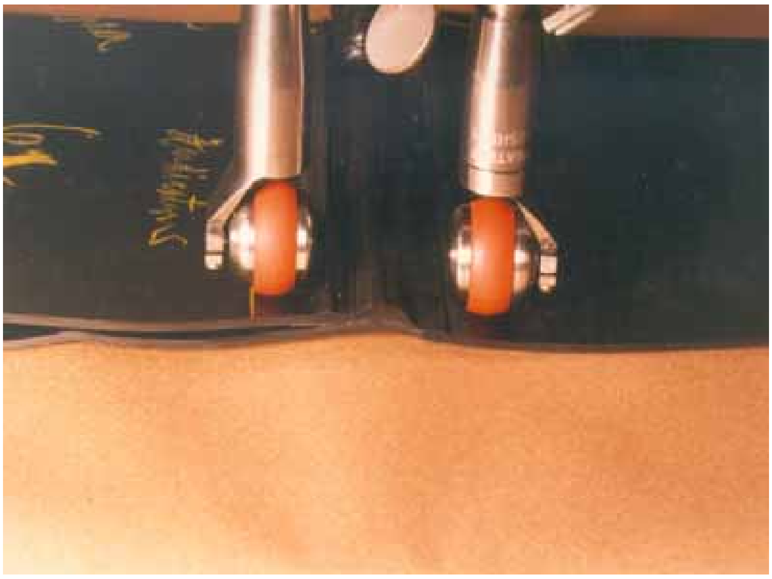

Figure 4. Pitch-catch ultrasonics using
wheeled transducers

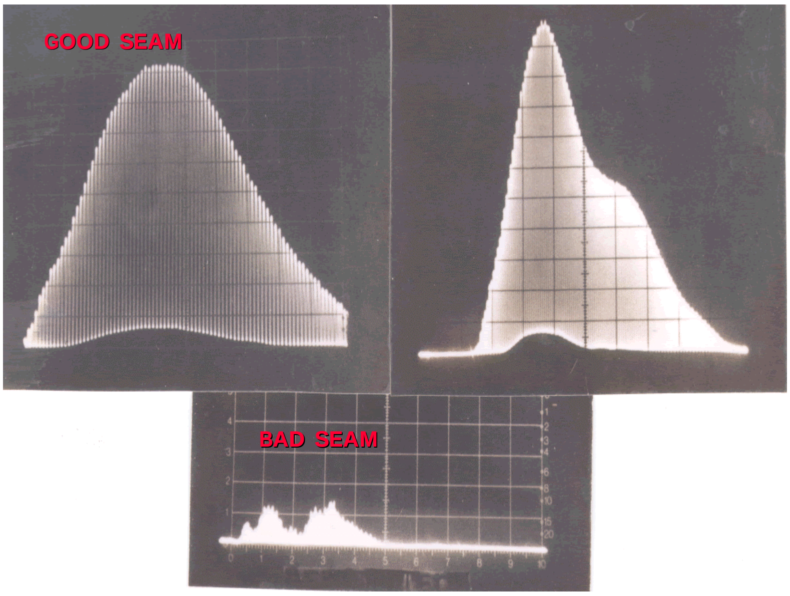

Figure 5. UT signals from good to poor seams

In Germany, Lüders (1998, 2000) thoroughly investigated the microstructure and subsequent durability of a variety of double wedge welds made under well defined welding parameters using specific welding machines and concluded that a good weld would result if the final seam thickness was between 0.3 and 0.8 mm less than twice the thickness of the geomembrane. Consequently, in Germany, the weld thickness is measured in the field using the old pulse-echo technique.

The same thickness reduction principle using the pulse-echo UT technique has recently been re-introduced into the USA, but without the same careful attention to welding machine characteristics and microstructural processes during welding. Measurements of weld thickness are made every 25 ft along double wedge seams, but not on extrusion seams. While this may provide satisfactory results some of the time it cannot be guaranteed to be effective since, without a better understanding of the welding processes, a given reduction in thickness can be achieved both by high temperatures/low pressures and by low temperatures/high pressures. The two conditions will generate quite different weld characteristics and performances.

If ultrasonics is to be used optimum use of present technology should be implemented. A continuous interrogation of the seam should be made using new transducer technology that does not require contact with the geomembrane. The signal should be passed through the weld interface from one geomembrane to the other, and a continuous record of the signal should be made for future examination as necessary. Such technology is also applicable to extrusion seams. It is inappropriate to use new technologies that will not monitor the full length of each type of seam and that will not provide a hard copy of the results.

3.3 *Infrared methods*

An alternative, and perhaps improved, technology is infrared thermography (IRT) (Peggs et al. 1994) in which the surface of a seam is heated a few degrees followed almost immediately by recording a thermogram of the surface temperature of the seam. A seam can be traversed at about 10 km/hr. Seam segments with good bonding will be cooler on the surface than segments of poor bonding. Heat will flow through the well-bonded area but will not flow away from the surface in poorly bonded areas or where there are voids within the interface. Different inclusions will affect surface temperatures in different ways depending on their thermal conductivity. Figure 6 shows a thermogram of a double wedge seam at the point where the speed control has been increased.

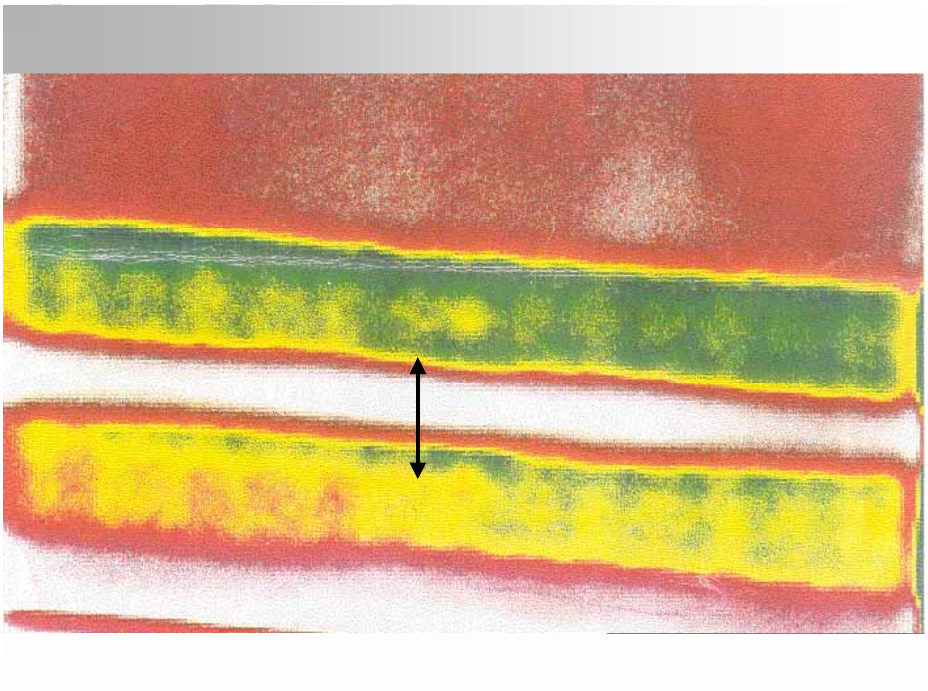

Figure 6. Black and white IR thermogram at change in speed setting (arrowed)

In the original color photograph red shows high temperatures and purple (the other end of the spectrum) shows lower temperatures. Each track of the weld is different, which is the rule rather than the exception. In a color photograph the colors change from red to yellow (from left to right in the lower track) and yellow to green in the upper track where the speed control has been changed (arrow in the center of the photograph). There is also a cyclic effect running along the seam that may be related to the temperature control on the wedge. When the different segments of the seam were peel tested only the track in the red segment showed any peel separation. Clearly the thermogram shows many more seam details than are reflected by conventional peel testing. Figure 7 shows two sections of weld made at the same temperature setting but at different speeds; the general quality of bonding is different and the widths of the weld tracks are different.

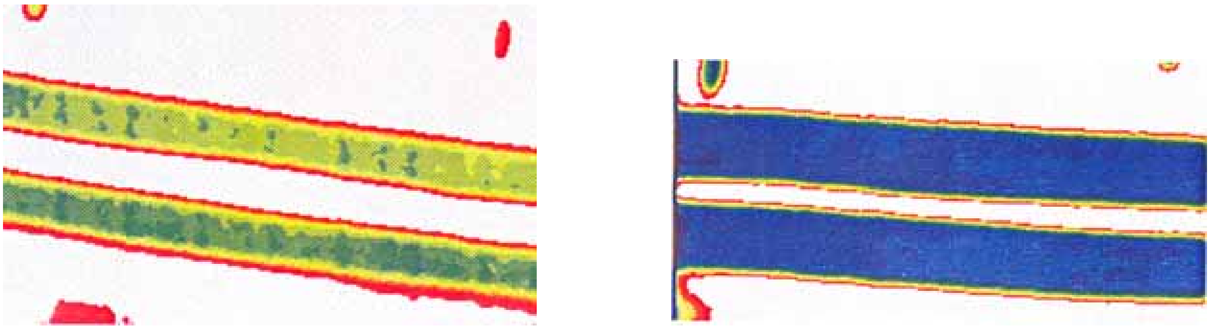

Figure 7. Weld made at same temperature but different speeds.
Left is green, right is blue

After suitable calibration of these characteristic observations a measurement of bond strength will be possible. A hard copy (videotape) of the complete weld can be made. Then with artificial intelligence the thermogram could be instantaneously analyzed to determine whether specific features are acceptable or should be rejected. Immediately a color-coded spot of paint could be dropped on the seam to indicate the location and type of defect. Ultimately, the equipment could be incorporated within the welding machine for feedback control of the welder.

The advantage of IRT over UT is that the former provides a detailed thermal map of the full width of each track of the weld while UT provides only an “average” picture of weld quality. The advantages of IRT and UT over conventional destructive testing methods are very clear – there is no need to cut holes in seams and to repair a good weld with an inferior weld, and every millimeter of weld can be evaluated.

3.4 *Whole liner surveys*

Useful information has been published by Nosko et al. (1996, 2000) on the locations and types of leaks found in geomembrane lining systems from electrical leak location surveys. On average 73% of leaks are caused by the placement of cover soils on geomembrane liners while only 24% are found in seams. Therefore seam quality is very important in uncovered liners of deep ponds, but not as important (practically) in covered liners. Thus, electrical surveys will identify leaks in the geomembrane itself as well as exactly locating leaks in seams, but again they will not assess seam bond strength. However, the International Association of Geosynthetic Installers (IAGI) , in a white paper authored by R. Koerner and G. Koerner (2004) proposes that if an electrical integrity/leak survey is to be performed it may be appropriate to widen the spacing of seam destructive samples from 1 in 150 m to approximately 1 in 800 m.

Another nondestructive technique for locating potential leaks in both seams and the geomembrane itself is IR spectroscopy using a portable multichannel gas analyzer, essentially a portable FTIR. Continuously analysing for methane, CO_2, and non-methane hydrocarbons, or other characteristic gases, it can locate very small leaks (Figure 8) in, for instance, municipal solid waste landfill caps (Peggs and McLaren, 2002) at rates of about 50 ha/day. Electrical surveys are performed at a rate of about 1 ha per day.

Figure 8. 5 mm punctures in landfill cap made by large rounded rock.

IR spectroscopy could be applied to bottom liners if a characteristic gas could be generated under the geomembrane, perhaps nitrogen from a slow release fertilizer.

3 SUMMARY

After many years of liner seam testing and leak location surveys it is time to put lessons learned into practice. When geomembrane seams are destructively tested in peel and shear no useful information is generated by measuring shear and peel strength. Shear elongation and peel separation do provide useful information. Ultrasonic and infrared thermography methods are available for assessing seam bond strength nondestructively. Electrical and infrared spectroscopy methods are available for evaluating complete liners.

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