IFAI Geosynthetics Conference
Feb. 10-13, 2019 | Houston, TX USA

Material Interface Types: Impact on Destruct Sample Failure Rates

Glen W. Toepfer, C.E.T,[1] and Brent J. Duganiero, C.E.T,[2]

[1]CQA Solutions, Ltd., 723A Phillips Avenue, Suite 201, Toledo, OH 43612-1351; e-mail: gwtoepfer@cqasolutions.co
[2]CQA Solutions, Ltd., 723A Phillips Avenue, Suite 201, Toledo, OH, 43612-1351; e-mail: brent@cqasolutions.co

ABSTRACT

This paper provides an in-depth examination of the failure trends of dual-track thermal fusion seam destructive samples based on interface types. Data analyzed from the destructive testing results of 7 actual projects provides unexpected insight into the destructive test failure rate differences between interface types. Current destructive sampling and tracking practices neglect the issue of texture variances within the weld interfaces. Failure to consider changes in the weld interface type during sampling and/or tracking is allowing inferior seams to remain in place, unrepaired and unnoticed. While these findings show the inadequacy of the industry's current sampling protocols, the paper also presents solutions to address these issues moving forward.

INTRODUCTION

The core goal of a containment system is to contain. Containment success lies in the minutia of a myriad of details where failure of any component may result in containment failure. Welding interface combinations are one of the more obscure details in containment construction that have been largely unaddressed in industry guidance documents. So, this prompts the question, does the welding interface type actually impact the quality of the welding/containment system? Research presented in this paper shows a substantial volatility in welding success when textured materials are a part of the welding interface types.

A key tool used in quality control/assurance of a containment system is destructive testing of welded seams to evaluate seam integrity. Fixed increment testing (i.e. 1 sample per 500 lineal feet) is commonly used on projects, whereas the Geosynthetics Research Institute (GRI) offers statistics based destructive test sampling (DS) protocols found in GRI-GM14 and GRI-GM20. EPA/600/R-93/182 also summarizes the common procedure for tracking failed DS. None of these methods suggest any mention of interface as a consideration for sampling or tracking.

Furthermore, the underlying principal of sampling and tracking is that some type of global cause of failure occurred which will universally impact all seaming performed in progression between the determined start of failure and end failure. This assumption also results in missing failing seams that occur as a result of changes in material interface, which are not linked to a global cause of failure. By looking at projects in which the traditional increment sampling (1 sample per 500 lineal feet of weld) resulted in tracking failed destructive samples over multiple interfaces using current tracking protocols, it can be shown that varying interfaces must be considered as part of any sampling regiment.

In order to understand the potential for failures based on material interface, it is important to look at the requirements for obtaining a quality fusion weld and see how different material interfaces impact these requirements. To evaluate the potential problems arising from traditional sampling and tracking methodology, data was obtained from different projects where traditional sampling and tracking methods were used. While the focus of this paper is on fusion welding of Polyethylene (PE) geomembranes with varying material interfaces, the data contained herein can be applied to other welding methods and the variances in other materials.

DEFINING THE INTERFACE

A thermal fusion weld interface is considered the area where the underside of the top sheet and the topside of the bottom sheet being welded overlap each other. This is the area where the welding will actually occur. There are various types of interfaces and these interfaces are categorized based on the texture and base resin combination of the interfaces that may or may not corollate to the actual sheet texture. An example of where sheet and interface texture might vary is in utilizing textured material that has a smooth edge for welding. If the smooth edges of two textured sheets are welded that would be a smooth/smooth (S/S) weld interface. If the smooth edge of a textured sheet is welded to an interior area of the textured sheet that does not have a smooth edge for welding that would be a smooth/textured (S/T) interface. The formula for labeling an interface is denoted by: (Top Sheet Texture)/(Bottom Sheet Texture). If the base sheet thickness or resins varied between the two materials in the welding combination, this would also need to be denoted in the labeling. Mixed material welds can be common on tie-ins.

Various project designs can create multiple interface types on a single project. A project utilizing a double-sided textured sheet for the entire project can still yield four different interfaces if the machine direction edges are smooth for welding purposes. Machine edge to machine edge would be a S/S weld. While, cross-direction to cross-direction would be a textured/textured (T/T) interface. Using interior portions of the sheet welded to the machine direction edge could yield textured/smooth (T/S) or smooth/textured (S/T) interfaces depending on the shingling. A double-sided textured sheet with no smooth welding edge (textured to edge of sheet) would only have a T/T interface unless being joined to smooth material on the project.

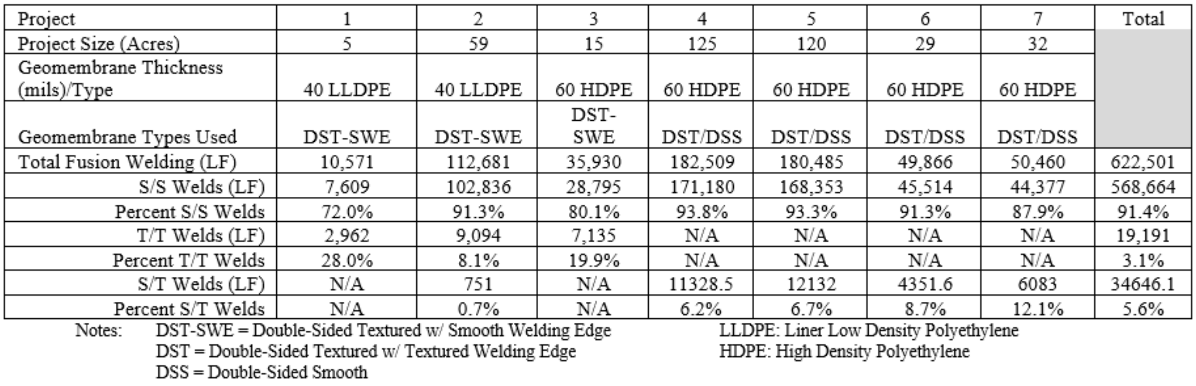
This paper evaluated projects with 3 different types of interfaces, each project utilized one resin type with all materials in the project having the same base nominal thickness in the sheet and each project presenting more than one interface type. The three interface types presented in these projects are: S/S, S/T (or T/S) and T/T. Please note that the research treats T/S and S/T as one category of interface type and not all projects had all 3 interface types.

PROJECT DATA

Data was obtained from seven projects that met the following criteria: multiple interface types, destructive test were taken and tracked on multiple interface types, the projects were fairly simple in terms of the design shape and all projects were representative of standard geosynthetic containment design and construction. The projects selected varied in size and material types although all were PE based materials. Projects 1-2 were cap installations whereas Projects 3-7 were cell installations. Project size ranged between 5-125 acres and base sheet thickness was either 40 or 60 mils. These projects were selected because they provided good sampling diversity while falling within typical US installation experiences such as: a variety of climates (desert, Midwest, Southeast, etc.…), diverse pool of installers (various experience levels, installation methods and company sizes), varying complexities, size and project type.

In order to assess the potential impact of interface types on a project, it is important to understand the amount of welding being performed on the various interfaces, the failure rates on the different interfaces, how they compare with industry standards and the amount of lineal feet of failure. The amount of welding of different interfaces will be impacted by the design, material selection (roll width, length), and panel configuration – the more complex the project is, the more likely there will be a higher percentage of secondary material seam interfaces. The projects selected were all fairly simplistic in nature but still resulted in a substantial amount of secondary interface seaming: even the smallest project 5 acres in size yielded nearly 3,000 lineal feet of secondary seam interface, see Table 1. Considering that the secondary seam interface may not even be adequately addressed in many destructive seam sampling regiments, it is important to look closely at the data to understand how various interfaces impact failure rates (FR).

Table 1: Project Data



Project	1	2	3	4	5	6	7	Total
Project Size (Acres)	5	59	15	125	120	29	32	
Geomembrane Thickness (mils)/Type	40 LLDPE	40 LLDPE	60 HDPE	60 HDPE	60 HDPE	60 HDPE	60 HDPE	
Geomembrane Types Used	DST-SWE	DST-SWE	DST-SWE	DST/DSS	DST/DSS	DST/DSS	DST/DSS	
Total Fusion Welding (LF)	10,571	112,681	35,930	182,509	180,485	49,866	50,460	622,501
S/S Welds (LF)	7,609	102,836	28,795	171,180	168,353	45,514	44,377	568,664
Percent S/S Welds	72.0%	91.3%	80.1%	93.8%	93.3%	91.3%	87.9%	91.4%
T/T Welds (LF)	2,962	9,094	7,135	N/A	N/A	N/A	N/A	19,191
Percent T/T Welds	28.0%	8.1%	19.9%	N/A	N/A	N/A	N/A	3.1%
S/T Welds (LF)	N/A	751	N/A	11328.5	12132	4351.6	6083	34646.1
Percent S/T Welds	N/A	0.7%	N/A	6.2%	6.7%	8.7%	12.1%	5.6%

Notes: DST-SWE = Double-Sided Textured w/ Smooth Welding Edge
DST = Double-Sided Textured w/ Textured Welding Edge
DSS = Double-Sided Smooth
LLDPE: Liner Low Density Polyethylene
HDPE: High Density Polyethylene

DESTRUCTIVE TEST RESULTS BY MATERIAL INTERFACE

All projects were unreinforced PE geomembrane seams; therefore, DS were tested using the applicable version of ASTM D6392 for laboratory testing. FR percentages include all field screening samples tested by the installer and documented by Quality Assurance (QA) personnel, but do not include samples tested by installer and not documented by the installer or QA. The current industry standard for fusion welds is that less than 5% of samples destructively tested should fail QA testing. Table 2 shows the average FR for all DS on a project ranged between 3.7-9.4% and the combined FR average for all projects was 5.4%. The S/S interface FR across all seven projects ranged from 0% to 6.9% and averaged 4.3%. However, the T/T interface FR ranged from 4.2% to 20.0% with an average FR of 10.8% and the S/T interface FR ranged from 0% to 25.0% with an average FR of 11.4%. The FR of the S/T and T/T interfaces were 271% and 257% respectively higher than the S/S interface. This data suggests a significant difference in FR between interfaces types. Project 1 highlights this issue as 100% of all project DS failures came from the T/T interface that had a 20% FR. So, 28% (by lineal foot) of the project seams were failing at a rate of 20%. These FR could likely be an under representation of total seam footage failures in the field due to DS tracking protocols; a substantial liability for the site owners.

Table 2. Destructive Sample Data by Material Interface

Project	1	2	3	4	5	6	7	Total
Project Size (Acres)	5	59	15	125	120	29	32	
Fusion DS	31	227	81	368	369	108	117	1,301
Failing DS	2	11	4	19	19	4	11	70
Failure Rate of DS (%)	6.5%	4.8%	4.9%	5.2%	5.1%	3.7%	9.4%	5.4%
S/S DS	21	168	57	328	328	100	101	1103
Failing S/S DS	0	4	3	13	17	4	7	48
Failure Rate of S/S DS (%)	0.0%	2.4%	5.3%	4.0%	5.2%	4.0%	6.9%	4.4%
Failing S/S Footage (LF)	0	205	1,080	850	430	90	220	2875
Failing S/S Footage as Percent of Material Interface Welded	0.0%	0.2%	3.8%	0.5%	0.3%	0.2%	0.5%	0.5%
T/T DS	10	59	24	N/A	N/A	N/A	N/A	93
Failing T/T DS	2	7	1	N/A	N/A	N/A	N/A	10
Failure Rate of T/T DS (%)	20.0%	11.9%	4.2%	N/A	N/A	N/A	N/A	10.8%
Failing T/T Footage (LF)	40	395	83	N/A	N/A	N/A	N/A	518
Failing T/T Footage as Percent of Material Interface Welded	1.4%	4.3%	1.2%	N/A	N/A	N/A	N/A	2.7%
Percent of Welding	N/A	0.7%	N/A	6.2%	6.7%	8.7%	12.1%	5.6%
S/T and/or T/S DS	N/A	0	N/A	40	41	8	16	105
Failing S/T and/or T/S DS	N/A	N/A	N/A	6	2	0	4	12
Failure Rate of S/T and/or T/S DS (%)	N/A	N/A	N/A	15.0%	4.9%	0.0%	25.0%	11.4%
Failing S/T and/or T/S Footage (LF)	N/A	N/A	N/A	145	50	0	140	335
Failing S/T and/or T/S Footage as Percent of Material Interface Welded	N/A	N/A	N/A	1.3%	0.4%	0.0%	2.3%	1.0%

As shown in Table 3, there were twelve instances where the tracking went from a textured interface (either T/T or T/S) to a S/S interface. In these instances, the first sample obtained on the S/S interface passed and bounding was completed in that direction. However, the question must be asked, "did those bounding samples actually track the true welding failure?" As shown on Table 1, Project 2 had 751 lineal feet of a third interface (S/T) accounting for less than one percent (0.7%) of all welding that did not get destructive tested. While the number of samples taken for the T/T interface certainly covers the frequency needed for both the T/T and T/S interface, it would be optimum to confirm seam integrity with a sample on all interfaces.

Table 3: Tracking to Alternative Interfaces

Project	1	2	3	4	5	6	7	Total
Project Size (Acres)	5	59	15	125	120	29	32	
# S/S Samples Tracked onto different interface	N/A	0	0	0	0	0	0	0
Results for each	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
# T/T Samples Tracked onto different interface	1	2	1	N/A	N/A	N/A	N/A	4
Results for each	Pass (1)	Pass (2)	Pass (1)	N/A	N/A	N/A	N/A	Pass (4)
# S/T and/or T/S Samples Tracked onto different interface	N/A	N/A	N/A	4	1	N/A	3	8
Results for each	N/A	N/A	N/A	Pass (4)	Pass (1)	N/A	Pass (3)	Pass (8)

Data from Tables 2 and 3 show that while the S/S interface regularly falls within normal FR parameters, the textured interfaces do not. This study did not examine any projects that were strictly a T/T interface but current evidence indicates that a higher failure rate would be expected. Additional study in this area should be performed.

STANDARD DESTRUCTIVE SAMPLING PRACTICES

Industry guidelines for DS are primarily found within the GRI protocols. The following statement within GRI-GM19a offers insight into various destructive sampling strategies suggested: "The spacings for taking field seam samples for destructive testing can be a fixed, or variable, interval or can be statistically related as provided in GRI-GM14 and GRI- GM20. These statistical processes describe a progression from the most restrictive interval of 1 per 500 feet (1 per 150 m) to the complete use and reliance of the electrical leak location survey (ELLS) method." These combined writings provide four DS methodologies as summarized below:

- Interval/increment sampling at 1 sample per 500 lineal feet of welding per operator/machine combination.
- GRI GM14 *Selecting Variable Intervals for Taking Geomembrane Destructive Samples Using the Method of Attributes* used on projects where more than 100 samples are anticipated (30 samples required just to start the process). This method uses statistical analysis to determine whether a batch of samples lies below, at, or above a predetermined acceptable failure rate. An initial sampling rate is used (often 1 sample per 500 lineal feet) and the sampling rate is adjusted throughout the project, <u>in samples per lineal feet</u>, based on the statistical results of the samples. If the failure rate for a batch of samples lies below the project's acceptable failure rate, the sampling rate spacing is increased above 500 lineal feet; conversely, if the failure rate lies above, the sampling rate spacing is reduced below 500 lineal feet.
- GRI-GM20 *Selecting Variable Intervals for Taking Geomembrane Destructive Seam Samples Using Control Charts* which can be used on smaller projects. This method also uses statistical analysis on a sample by sample basis to determine whether the failure rate lies in an acceptable window. An upper acceptable failure limit and a lower acceptable failure limit comprise the acceptable window and the <u>sample spacing is adjusted accordingly</u> from an initial sample spacing (often 1 sample per 500 lineal feet) to keep the failure rate within this window.
- Replacement or reduction of destructive sampling by technologies such as electrical leak location surveys (continuity/leak testing). Since DS are for the purposes of testing seam strength the authors are unsure how a continuity test is a relevant replacement for strength testing. No further dialogue will be presented on this option.

None of these methods has any guidance or assurance that different material interfaces will be sampled or tracked according to interface type. The fact that destructive sampling guidelines and specifications typically do not address changes in material interface is surprising given that trial seam requirements typically found in these same project specifications require passing samples for each material interface before they can be welded. Not only is each interface required to be tested during a trial seam, but passing samples are required for each operator and machine combination doing the welding of each interface.

STANDARD TRACKING

When a DS fails, the failure must be tracked to ensure that the start and end of the area of failure is clearly identified and remediated. This is called "bounding" the sample/failure. Tracking is accomplished by identifying the operator/machine combination that welded the failed sample (FS). Then identifying ("tracking") the welding they performed immediately before and after the FS. As mentioned in EPA/600/R-93/182, most CQA Plans suggest the QA team mark bounding samples in the tracked seams 10 feet before and 10 feet after the original FS and mark those two spots as the "before" and "after" pathways for two new DS tests. If both new DS pass then the original failure is considered "bound". However, if one or both tracking samples fail, the tracking must continue in the direction (before and/or after) as the newest failure(s) occurred. This process is the same regardless of sampling frequency determination method.

DS are labeled in the order they are marked and/or cut in the following manner: the first DS would be labeled “DS1”, the second “DS2” and so on throughout the project. Tracking DS are labeled with a “B” for before samples and an “A” for after samples such as: DS1A and DS1B. If one of the tracking DS fails, the failures are typically numbered such that DS1A2 would be the DS after DS1A had failed.

The standard tracking process is illustrated using Figure 1 and Figure 2 below. For the purpose of this exercise, assume that the panels are all double-sided textured geomembrane with smooth welding edges in the machine direction (length). Therefore, the only seams that have an interface other than S/S are seams P2/P3 and P5/P6 which have T/T interfaces. Also, assume the same operator and machine combination performed the welding of all seams: the seaming sequence is listed using circled numbers and seaming occurred in numerical order. The arrow extending from the circle indicates the direction the seam was welded. For clarification, welding order would be P2/P3, P1/P2, P1/P3, P2/P4, P3/P4, P5/P6. Also assume that DS1 taken on seam P2/P3 failed (a T/T seam).

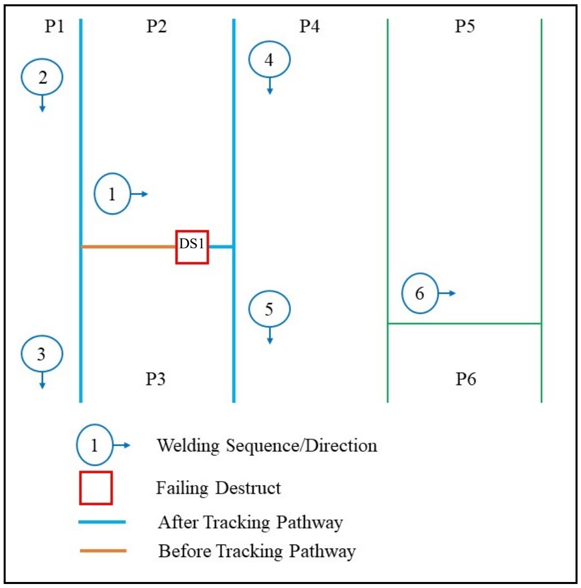


Figure 1: Seaming

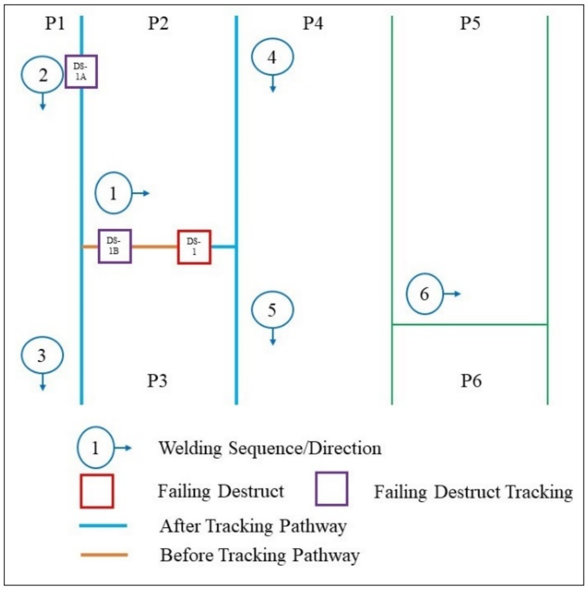


Figure 2: DS Placement

Figure 2 illustrates the standard method of tracking failed destructive samples, with the before and after tracking pathways shown. DS1B would be placed on P2/P3 in the before direction of the seam to see if the DS can be bound. If DS1B passes; the before direction is bound. If DS1B fails: all seaming on P2/P3 before DS1 would need to be capped and the before tracking would end because there are no previous seams. Likewise, the after sampling would work forwards onto P1/P2, P1/P3, P2/P4, P3/P5 and P5/P6. Figure 2 highlights the after tracking seam range that will most likely bound the sample unless a catastrophic global seaming failure occurred for this operator/machine combination.

In this example, which is fairly representative of field construction practices, the after sample would be obtained on a S/S interface. If the after-sample passes, seam P5/P6, which was welded by the same operator/machine and is the same T/T interface as P2/P3 may never be evaluated. So, given the data presented from the seven projects in this paper, does a passing S/S weld truly represent that the T/T welds are also likely to pass? It is the author’s supposition that this is not representative of the quality of the T/T seams welded on that day by that operator/machine combination. However, the industry standard protocol has been met regardless of the weld quality of the project.

SAMPLING PROTOCOLS & INTERFACES

QA personnel can be required to mark DS every 500 lineal feet regardless of what issues/suspect areas are observed with no consideration of the risk level associated with that arbitrary location. This process can degrade the quality of the project by causing obvious failures to go unaddressed or poor DS locations such as the sump or other high stress areas being subjected to unneeded holes and repairs. Project quality increases when qualified QA's are allowed within certain parameters to select DS locations based on the needs of the specific project. The following sampling protocols were utilized for all seven projects:

- Tracking samples on the direct welding path rather than deviating or adjusting to account for different interfaces encountered on that pathway.
- QA sampled all interface types as appropriate.
- QA marked samples where they were needed to ensure quality throughout the project – not simply wheeling off 500-foot intervals.
- QA personnel balanced the destructive sampling where appropriate, so if a textured interface was more problematic more samples were taken on this interface and less on the S/S interface still yielding an end product of 1 sample per 500 lineal feet.

The flexibility in these protocols provided the QA team the ability to increase project quality without increasing cost or damage to the liner system's integrity. For instance, Project 4 had an overall sampling rate of 1/496 lineal feet with the rate on the textured interface being 1/283 lineal feet while the S/S interface was 1 sample per 521 lineal feet. A larger project afforded the opportunity to also increase S/S sampling when problems arose and decrease the sampling when no issues were present. It is important to note that the amount of the secondary interface welding is substantial and adds up quickly, see Table 1 for details.

FAILURE EVALUATION

All of the samples listed on these projects failed during the peel test – no samples were attributed to shear failure. Of the failures on the S/S interface, the majority were peel adhesion failures exceeding maximum project requirements with a few having only low strength failures. The failures on the T/T interface were all peel adhesion failures, with some also exhibiting substantially low strength before peel incursion failure.

It is important to try and diagnose the cause of a failure rather than accept the failure and move on with remediation of the damage. Diagnosing the cause of a failure and sharing that feedback with the installer is critical to maintaining quality. The important question to ask during the diagnosis is, "Does the seam show characteristics associated with any of the four requirements for obtaining a quality weld – absence of moisture or dirt, proper pressure, proper heat, and proper contact time?" If a sample fails in the field, the coupons can be viewed by personnel and an assessment can be made; however, this luxury is not afforded if the samples are shipped off-site to a third-party laboratory. Maintaining an archive sample to look at when a sample fails may also afford the ability to diagnose the problem.

Predominant cause of S/S interface failures was failure to keep the seam clean and/or dry. Dirt was also one of the major contributors to the textured interface failures, along with failure of the operator to change settings prior to welding, which resulted in a lack of heat penetration. Although pressure could not be directly measured with the welding apparatuses used on these projects, evidence suggests there were pressure issues that caused failure as well. Field personnel often noted uneven track patterns between the two seams of a dual-track fusion welder and barely visible penetration – both indicators that something was wrong with the pressure.

THE BASICS OF A QUALITY FUSION WELD

There are four basic requirements for a sound fusion weld: a clean, dry interface between sheets, proper heat, proper pressure, and proper contact time. Variances in any of these four aspects can result in inferior welds. Table 4 illustrates thickness differences between smooth and textured geomembranes.

Textured material has more variables than smooth material such as asperity height and asperity density. Additionally, textured sheet is inherently thicker: for instance, a 1.5 mm (60 mil) single-sided textured sheet averaging 1.4 mm (57 mils) of thickness will be approximately 1.96 mm (77 mils) thick if the asperity height is 0.5 mm (20 mils) whereas the total thickness will be approximately 2.46 mm (97 mils) for a double-sided textured sheet with the same 0.5 mm asperity height. The asperities themselves result in a sheet that is not as uniform in thickness as a smooth sheet. Cleaning and drying textured material present challenges as well.

Table 4. Material Thickness Comparison: Smooth & Textured Geomembranes

60 mil HDPE	**Agru**	**Atarfil**	**GSE**	**Solmax**
	mils (mm)	mils (mm)	mils (mm)	mils (mm)
Minimum Values				
60 mil Smooth	54 (1.35)	54 (1.35)	54 (1.35)	54 (1.35)
60 mil Single-Sided	51 (1.28)	52 (1.3)	54 (1.35)	51 (1.28)
60 mil Double-Sided	51 (1.28)	52 (1.3)	54 (1.35)	51 (1.28)
Max Values				
60 mil Smooth	N/A	N/A	N/A	N/A
60 mil Single-Sided	N/A	N/A	N/A	N/A
60 mil Double-Sided	N/A	N/A	N/A	N/A
Avg Values				
60 mil Smooth	60 (1.5)	60 (1.5)	60 (1.5)	60 (1.5)
60 mil Single-Sided	57 (1.43)	57 (1.43)	60 (1.5)	57 (1.43)
60 mil Double-Sided	57 (1.43)	57 (1.43)	60 (1.5)	57 (1.43)
Asperity Values				
60 mil Single-Sided	20 (0.51)	21 (0.525)	18 (0.45)	16 (0.4)
60 mil Double-Sided	20 (0.51)	21 (0.525)	18 (0.45)	16 (0.4)
Avg Total Thickness				
60 mil Smooth	60 (1.5)	60 (1.5)	60 (1.5)	60 (1.5)
60 mil Single-Sided	77 (1.925)	78 (1.95)	78 (1.95)	73 (1.83)
60 mil Double-Sided	97 (2.425)	99 (2.475)	96 (2.4)	89 (2.23)

Added thickness of a textured sheet should cause welders to reduce machine speed (increase contact time), increase the heat, or both when switching from a S/S weld interface to a T/T interface. Table 5 illustrates this difference observed in trial welds between the two materials for two different fusion machine operators on a 1.5 mm HDPE project. Note that the machine speed setting is a nominal value that often does not equate to a true distance per time correlation (i.e. setting of 10 does not mean the speed is 10 feet per minute, etc. nor that two machines with the same setting are running the same speed). At the time of writing, the fusion welding equipment being predominately used in the United States does not monitor pressure applied to the nip rollers. While operators may fail to change settings between interfaces, this should not be dismissed as the sole reason for failure because otherwise the samples tracked from the textured interface to the smooth interface would have shown some failures as well.

Table 5. Machine Settings Adjusted for Different Materials.

	Ambient Temp (degrees Fahrenheit)	Wedge Temperature Setting (degrees F)	Machine Speed Setting (Nominal Value)
Machine#1, Operator#1: S/S	78	800	6.5
Machine#1, Operator#1: T/T	76	800	6.0
Machine#2, Operator#2: S/S	78	800	7.4
Machine#2, Operator#2: T/T	76	800	5.5

Note: Many machines used in the US do not directly correlate speed settings to feet/minutes. So nominal values were used in this table.

SOLUTIONS

The need to ensure destructive sampling is in fact obtaining representative samples of all material interfaces is imperative to maintaining high quality installations. However, sampling strategies must be balanced with a risk vs. reward strategy such that extra holes in the geomembrane are minimized. Each project should have minimum requirements for ensuring that each interface is indeed tested. From there, adjustments in the sampling program may need to be evaluated on a regular basis. There are six fundamentals that should be routine:

1. Designers must consider material interfaces and use a risk assessment tool to evaluate if additional material interfaces could compromise the long-term quality of the project.
2. Specifications written such that each material interface is thoroughly tested in a manner that does not compromise the integrity of the liner system. This includes trial seams, interval destructive samples, and end coupons.
3. A QA program that ensures QA oversight of the testing of: trial seams, end coupons, and field-testing of interval DS. This includes developing a minimum frequency of sampling on all interfaces. In regard to the DS, the GRI-GM20 control chart could be used separately for each interface type, in conjunction with end coupons to ensure sampling of each material interface.
4. The QA program should include comprehensive monitoring of the three primary welding parameters: weld temperature, weld speed, and welding pressure. With current advances in technology and this data becoming readily available, it should provide a useful tool in analyzing seam quality and identifying trends.
5. When failures occur on one interface and are tracked progressively to another passing interface, that first failing interface should undergo additional scrutiny on previous and subsequent welded seams. End coupons would be a good starting place in this regard, with a minimum of three peel samples required from each end tested under the observation of a competent QA person.
6. Require destructive test data be reviewed on a regular basis and scrutinized for trends. Interfaces that appear problematic may be targeted more while at the same time decreasing sampling on those that appear sound such to balance out the overall sampling rate but using the samples to the best potential available.

CONCLUSION

While it is known that different material interfaces pose challenges in obtaining sound welds, sampling procedures fall short of thoroughly evaluating the integrity of each interface, especially when tracking failed samples. By improving protocols for sampling different interfaces as well as when tracking failed samples across multiple interfaces, the risk of failing to identify bad welds on difficult interfaces can be substantially reduced. Sampling strategies that properly target hard to weld interfaces is another step toward protecting our environment for the future.

REFERENCES

Agru America, Inc. (2018) *Smooth Liner* product data sheet, Georgetown, South Carolina, USA.

Agru America, Inc. (2018) *MicroSpike Liner* product data sheet, Georgetown, South Carolina, USA.

Atarfil. *Atarfil HD v1* product data sheet, Complejo El Rey, Granada, Spain.

Atarfil. *Atarfil TM/TMT v1*product data sheet, Complejo El Rey, Granada, Spain.

Environmental Protection Agency. *EPA/600/R-93/182 Technical Guidance Document: Quality Assurance and Quality Control for Waste Containment Facilities,* pg. 151,159, Cincinnati, Ohio 1993.

Geosynthetics Research Institute. (2013) GRI GM14 *Selecting Variable Intervals for Taking Geomembrane Destructive Seam Samples Using the Method of Attributes,* Folsom, Pennsylvania, USA.

Geosynthetics Research Institute. (2017) GRI-GM19a*, Seam Strength and Related Properties of Thermally Bonded Homogeneous Polyolefin Geomembranes/Barriers*, Folsom, Pennsylvania, USA.

Geosynthetics Research Institute. (2003) GRI-GM20*, Selecting Variable Intervals for Taking Geomembrane Destructive Seam Samples Using Control Charts*, Folsom, Pennsylvania, USA.

GSE Environmental. (2014) *HD Smooth Geomembrane* product data sheet, Houston, Texas, USA.

GSE Environmental. (2014) *HD Textured Geomembrane* product data sheet, Houston, Texas, USA.

Solmax. (2016) *HDPE Series, 60 mils Black Textured* product data sheet, Varennes, Quebec, Canada.

Solmax. (2016) *HDPE Series, 60 mils Black Single Sided Textured* product data sheet, Varennes, Quebec, Canada.

Solmax. (2016) *HDPE Series, 60 mils Black Smooth* product data sheet, Varennes, Quebec, Canada.