

Inspection of Polyethylene Fusions and Electrofusions

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Abstract

For buried gas distribution pipelines, the majority of the future risk profile is set when the pipelines are installed. In effective Pipeline Safety and Asset Management Systems, then, it is critical to ensure the integrity of new pipeline installations. With the excellent projected longevity of current generation PE gas piping, a key component of ensuring future pipeline integrity must be centered on ensuring the integrity of the joining techniques. A novel approach is presented for non-destructive evaluation of fusion joints. The technology is based on ultrasound but manages to be more effective than previous ultrasonic methods due to a unique approach to analyzing the sound waves. The approach is described and case studies involving the application of the technique to electrofusion joints are presented. The technology is seen to be highly effective in identifying fusion abnormalities.

Background

Electrofusion fittings are seeing increased use in gas distribution pipelines. While electrofusion (EF) joints can be highly reliable, quality components and installation techniques are necessary for ensuring the long-term integrity of the joints. The Plastic Pipe Database Committee (PPDC) has identified infant mortality failures in electrofusion joints¹. Similarly, a comprehensive study of electrofusion joints in the UK² found that 20% of field joints sampled failed in destructive testing. The primary causes of failure in this study were identified as:

- Inadequate clamping or misalignment: 34%
- Contamination: 29%
- Poor scraping: 26%
- Other: 11%

Proper qualification programs, proper installation procedures and operator training best practices can significantly mitigate these potential failures³. A complete integrity program should also include some level of follow-up inspection of joints to ensure the effectiveness of the installation procedures and operator training programs. A challenge with EF joints, as the fusion interface is hidden from view by the body of the fitting, is that simple visual inspection provides little information on whether a quality joint has been prepared. This is particularly true for issues of contamination and poor scraping. An effective and reliable non-destructive evaluation methodology would provide a valuable tool for inspection of joint quality to ensure pipeline integrity, providing the important 'check' function in the Plan – Do – Check – Act (PDCA) cycle.

Ultrasonic testing has emerged as the most likely technique to provide non-destructive testing for PE electrofusion welds. In ultrasonic testing, a high pressure wave is fired from a piezoelectric probe into a weld and records the received echoes from the material interfaces and any reflectors that may be present in the sample. There have been challenges, however, in developing *reliable* ultrasonic

¹ Plastic Piping Data Collection Initiative Status Report, December 2014.

² UK WIR Report Ref No 10/WM/08/43, "Leakage from PE Pipe Systems", 2011

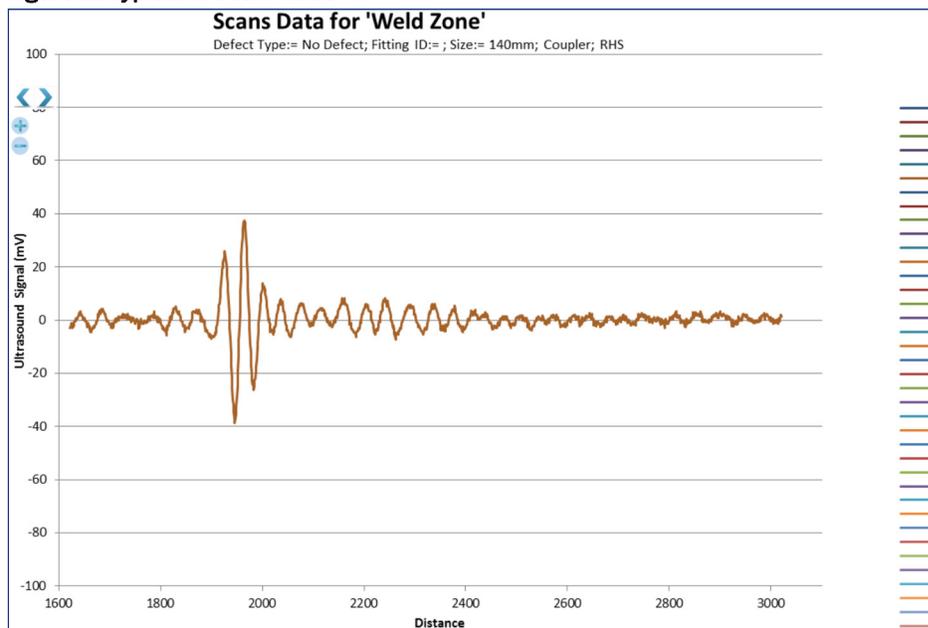
³ Qualification Program for Electrofusion Fittings, JANA Corporation, 2015

technologies. This paper presents a novel ultrasonic NDT approach that has been shown to be highly reliable in identifying the primary failure modes observed in the field.

Ultrasonic Inspection of Electrofusion Joints

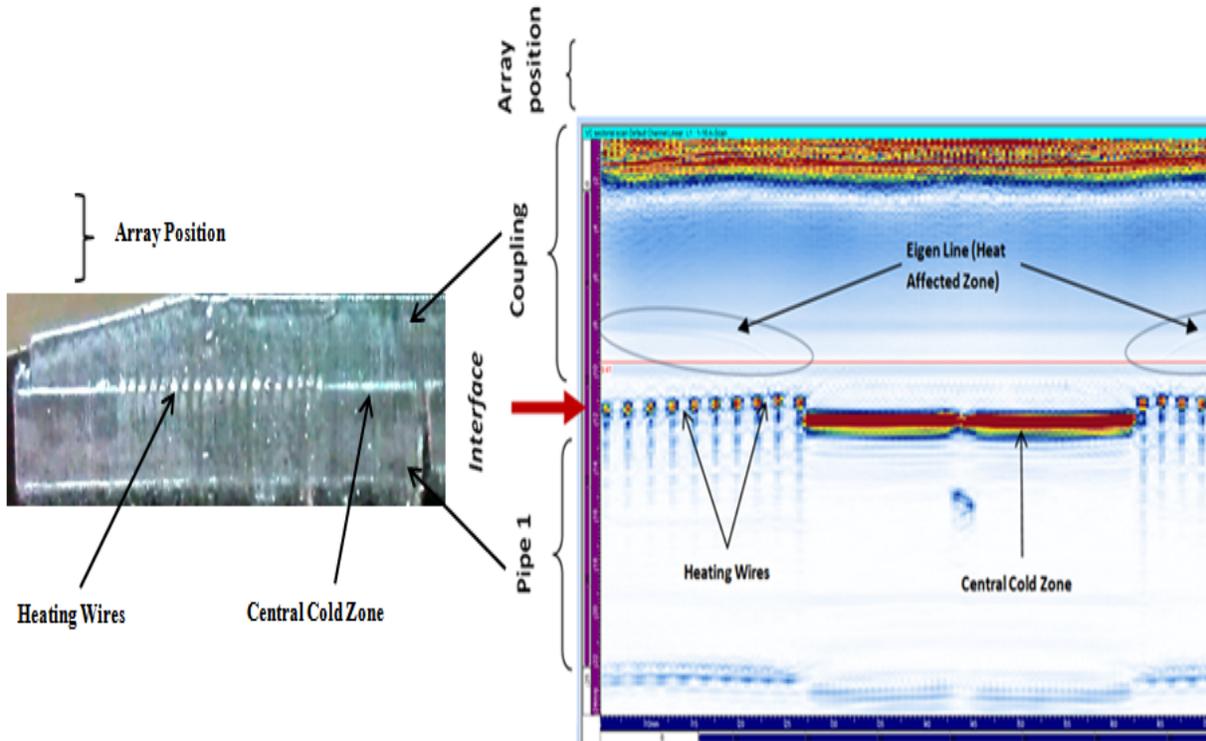
The goal of ultrasonic inspection is to “see” the hidden regions of an electrofusion joint in order to assess joint quality. There are two primary ways that ultrasound can be used on plastic pipe joints. The first method is to use a pulse-echo system, using a single probe transducer and presentation of results in the form of an A-Scan (time domain trace). This is a very simple and inexpensive system using only one probe and modest electronics. Figure 1 shows a typical A-Scan trace—an X, Y plot showing energy received (Y axis) vs time (X axis). Information from the material interfaces and other reflections are contained in the sinusoidal wave shape.

Figure 1: Typical A-Scan Trace



The second method is to use a phased array, comprising multiple piezoelectric elements which can be individually addressed and controlled. Here, electronic scanning is carried out, where a subset of elements are excited, the relative phase of the excitation that is applied to each element will cause the ultrasonic energy to be focused to a particular depth in the sample being interrogated—usually to the weld interface. The output from the phased array is referred to as a B-Scan. A typical B-Scan output is shown in Figure 2 (using a 128 element probe system).

Figure 2: Typical B-Scan Trace



The B-Scan output appears as a picture of a section through the weld, with the reflections from the heating wires, material interfaces and other reflection points identified. The B-Scan technique is typically 10-20 times more expensive than the single probe, much larger to handle and requires an expert to interpret the results.

Identifying the Primary Failure Modes with Ultrasonic Inspection

As discussed previously, the primary integrity issues for EF joints in the field are inadequate clamping and misalignment, contamination and poor scraping. These failures are a result of voids and/or improper melting (cold-zone) and lack of bonding at the pipe-fitting interface. An effective NDT technology must be able to identify voids, cold zones and contamination. While voids are generally readily detected with ultrasonic inspection, the more subtle issues of improper melting (cold zone) and lack of bonding at the joint interface that arise from surface contamination are much more challenging to detect.

Inadequate Clamping and Misalignment

Inadequate clamping and misalignment, including pipe ovality, are seen to contribute to a significant proportion of observed field integrity issues. The result is typically voids or regions of improper melting (cold zones) and bonding. Under-heating of the fusion joint can also leave voids in the form of an air gap between the pipe and fitting due to lack of melting of the polymer interfaces. Ultrasound works very well to show voids, as the pressure wave is reflected strongly

from the polymer/air interface. Observing improper melting (cold zones) and bonding has been seen to be much more challenging with existing technology.

Contamination

Contamination results in a weakened joint interface or, for liquid contaminants that volatilize during the fusion process, voids. Contamination type defects are typically more difficult to 'see', particularly mud contamination. The wavelength of the sound characteristically used for ultrasonic inspection is of the order of 0.4mm, which makes it impossible to detect reflections from mud particles themselves (which are typically 10 microns diameter or less). Instead, it is necessary to 'see' reflections from the structural differences that are caused by the mud. These defects are not obvious in the B-Scan output and, hence, the reduced ability to see mud contamination has been a serious issue for the acceptance of Ultrasound NDT.

One confusing in the ability to see contamination is that ultrasound can quite easily see contamination by Talc. Talc has a structure (platelets) that reflect the sound pressure waves quite well and, as such, they can be seen on B-Scan images. This can 'lull' the researcher to believe the system can see 'contamination'. It is essential, therefore, that NDT systems are tested on mud and other actual contaminants and not just Talc.

Improper Scraping

Over-scraping of the pipe surface can result in the formation of voids at the weld interface due to the lack of tight fit between the pipe and EF fitting surfaces. Again, ultrasound works very well to show these voids, as the pressure wave is reflected strongly from the polymer/air interface. If the issue is more subtle and results in cold zones, these can be more difficult to detect.

Under-scraping or no scraping of the pipe surface can leave a contaminant layer on the pipe, leading to a situation similar to that observed for general contamination. Again, it is necessary to 'see' reflections from the structural differences that are caused by this surface contamination.

A Cost Effective and Reliable Ultrasonic Inspection Tool

Based on field experience in testing EF joints and the limitations of B-scan technology—particularly its bulkiness, expense and questionable accuracy in detecting contamination—a research program was initiated to develop a more practical, cost effective and accurate technology. This led to the development of a simple-to-use, cost-effective and highly accurate tool based on A-scan technology. The key to this methodology was the development of a novel approach for analysis of the sound waves. The sinusoidal wave form output from an A-scan contains a significant amount of information about the substrate through which the sound passes. Good welds with no defects produce a very distinctive sinusoidal trace where the 'ring down' from the wires is overlaid by the various weld reflections, resulting in slight changes to peak height and received frequency. Voids show up as additional peaks. Contamination produces very unique and easily identifiable wave forms.

Simple to Use

The tool is simple to use as it is compact, provides a green/red pass fail output and its patented technology ensures that accurate readings are taken. Analysis of a 4" electrofusion coupling takes 5 - 15 minutes.

The developed tool is hand-held, rugged and can be connected to a portable tablet or laptop (Figure 3). Given the very low profile of the end of the probe, it can be used in very tight areas and measure right up to shoulders, nipples and other molding irregularities. The probe needs to be in direct contact with the surface, which is achieved using a coupling gel.

The A-Scan output—a string of numbers representing the power received by the receiver in time increments—is processed to provide a green/red light for a pass or a fail of the joint. It is also possible to determine the type of void and, hence, the most likely cause of the joint failure so that corrective action can be taken. Roughly thirty readings are taken each second. Repeatability is excellent so averaging of the spectra is not required.

One requirement for A-scan technology is that the probe is held vertically to the weld to ensure maximum sound reflection. Even small deviations from the vertical can result in poor results, which may be one reason why A-Scans have not become popular. This issue has been resolved by the development of a patented software solution that ensures results cannot be taken until the probe is in the vertical position, confirming that the operator obtains an accurate assessment of the joint.

Figure 3: Ultrasonic Inspection Tool



Cost Effective

As the equipment required for A-Scan ultrasonic inspection is very simple, it is a very cost effective methodology. With a low per-unit cost, the tool can be employed widely in the field, even to the point of enabling each fusion crew to have joint inspection capabilities. This, coupled with the ease of use, provides a viable means of achieving 100% joint inspection.

Highly Accurate

The key feature of the developed technology is the high level of accuracy in identifying all failure modes observed in the field. The system has now been verified through testing of over 100 pipe welds of various sizes between 1" and 20" diameter. Excellent correlation has been achieved for voids, cold-zones and contamination detection. The recent developments in spectral processing enabled identification of defects with 100% accuracy on the latest set of welds run.

In order to verify and calibrate the NDT system, an extensive testing program was initiated on a wide range of joints (different sizes and manufacturers) with a range of defects both intentionally created and from actual field specimens. The NDT results were correlated with the results of destructive testing⁴.

Specifically this NDT technique can identify the following type of defects, giving a green/red light (pass/fail) indication.

- Voids: Readily detected due to the PE-to-air interface, which produces a significant response where position on the x axis of the spectra varies depending on the void location
- Cold Zones: The area where there is a tight interference fit of the pipe inside the coupler but not within the fusion zone. There are two interfaces (the pipe and the EF fitting) with a very small air gap between. This gives significant peaks which are impossible to misinterpret. Their position on the x axis of the spectra is fixed with respect to EF fitting thickness
- Contamination: Assessed through a novel spectral analysis methodology and correlated with reference spectra and destructive testing to provide a green/red (pass/fail) response. Contamination results the PE in the coupler and the pipe not flowing into each other sufficiently to enable chain entanglement during the melt phase of the welding. This results in a specific spectral pattern.

Field Use of Technique

The developed ultrasonic technology is now being trialed in the field for examination of electrofusion joints with a high level of success. Excellent correlation between the NDT results and destructive testing results is seen.

As discussed previously, the most difficult defect to detect in NDT assessments is mud contamination. Figure 4 provides a comparison of the NDT contamination coefficient (determined by the analysis software based on the spectral trace) and the elongation at break in the WIS pull test for a series of field joints with varying levels of contamination. There is a very good correlation, so the A-Scan NDT

⁴ UK WIS standard pull test (WIS 4-32-08: Double Cantilever Cleavage Test)

methodology is able to detect not only contamination but also the actual level of contamination with good accuracy. This correlation can be used to set pass/fail criteria for an inspected joint based on the observed contamination coefficient.

Figure 4: Elongation and Break versus NDT Correlation Coefficient

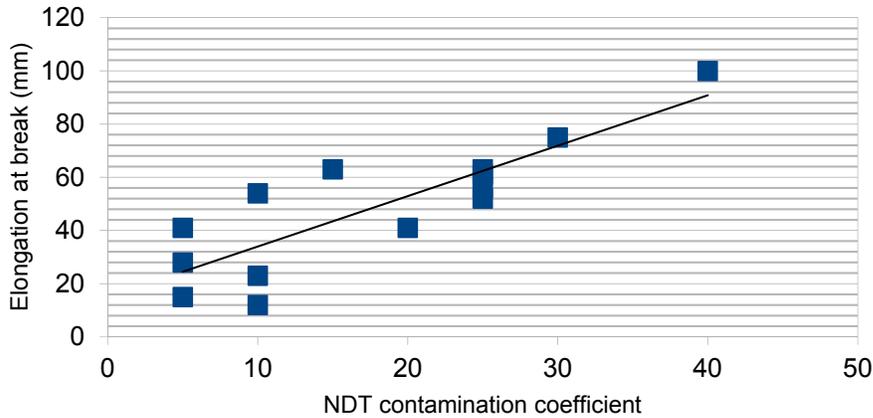


Table 1 provides a summary of NDT and destructive test results for a 140 mm electrofusion joint. As can be seen from the results, there is a good correlation between the NDT results and the destructive test results. For all areas of the joint where heavy contamination was detected in the NDT assessment, the joint section failed the destructive testing (brittle failures in pull test). For areas with no defect identified, all specimens passed the destructive testing (ductile failures). Areas with slight contamination identified in the NDT analysis showed borderline results in the destructive testing. Similar excellent correlation has been observed across a broad range of field joints. Testing and assessment of this methodology is ongoing.

Table 1: Comparison of Destructive Testing Results with NDT Assessment

Test Position around Weld	WIS Pull test data				NDT Assessment
	Peak Load	Extension at break	Visual Assessment	WIS pass/fail	
L4	765N	40.7mm	Mixed brittle/ductile	Borderline	Medium contamination
L16	870N	62.6mm	50% brittle with 50% high extension ductile	Fail	Medium contamination
L20	945N	75mm	100% ductile	Pass	No defect
L22	801N	51.8mm	10% brittle	Pass	Slight contamination
L30	834N	63.5mm	Mixed brittle/ductile	Borderline	Slight contamination
L32	1026N	56mm	Mixed brittle/ductile	Borderline	Slight contamination
L48	672N	54.2mm	100% brittle	Fail	Heavy contamination
R4	1029N	15.5mm	100% brittle	Fail	Heavy contamination
R10	962N	71mm	100% ductile	Pass	No defect
R20	798N	23.1mm	100% brittle	Fail	Heavy contamination
R34	770N	11.7mm	100% brittle	Fail	Heavy contamination
R36	865N	27.8mm	100% brittle	Fail	Heavy contamination
R40	884N	60.7mm	Mixed brittle ductile	Borderline	slight contamination
R46	735N	41.4mm	100% brittle	Fail	Heavy contamination



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An Effective Approach for NDT Inspection of Electrofusion Joints

The primary integrity issues for EF joints in the field are inadequate clamping and misalignment, contamination and poor scraping. These failures are a result of voids and/or improper melting (cold-zone) and lack of bonding at the pipe-fitting interface. An NDT inspection method that is easy to use, cost effective and highly accurate has been developed, providing operators with a viable means of field inspection of EF joints to ensure pipeline safety and integrity. Testing and correlation of the methodology with field prepared joints is ongoing.