Non-Destructive 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. At AGA's 2015 Operations Conference, JANA presented a novel approach 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. An update on the development of the technology is presented, including validation results.

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 joints[1]. Similarly, a comprehensive study of electrofusion joints in the UK[2] 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%

Ultrasonic Inspection of Electrofusion Joints

The goal of ultrasonic inspection is to "see" the hidden regions of an electrofusion joint 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.

[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

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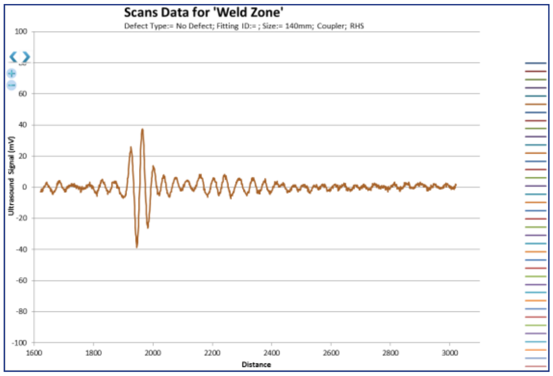
Figure 1: Typical A-Scan Trace



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.

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.

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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 testing[3].

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.

Validation Methodology

To validate the performance of the technology in North American gas distribution systems, a Validation Plan was developed to represent typical pipe, fitting and fusion conditions seen in the field. The Validation Plan includes the creation of 2" electrofusion coupling joints with defects, analysis of the joints using the NDT technology and then destructive testing of the joints to confirm the accuracy of the technology.

To properly validate the NDT technology with expected field conditions, a number of samples were made to recreate fusions typically seen in the field:

- Good Joint
- Water Contamination
- Mud Contamination
- Under Insertion
- Over-scraped Pipe
- No Scraping (Oxidized)
- Interrupted Fusion Cycle

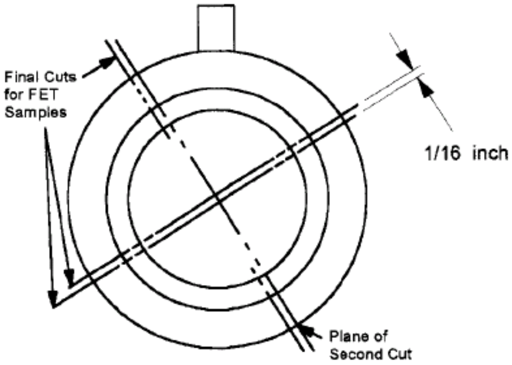
Once each joint was created, a grid was placed on the fittings in order to measure at discrete points around the joint as shown in **Figure 2.** An NDT analysis was then completed and the results were recorded for each point around the joint.

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

Figure 2: NDT grid on the outside surface of a 2" coupling

After completion of the NDT analysis, destructive testing was completed in general accordance with Section 9.4.3 of ASTM F1055-13 (Fusion Evaluation Test (FET) of Sockets) to verify each NDT reading. Samples were cut from the joints, per **Figure 3**. Although the standard requires a minimum of four strips from each half of the fitting, for data purposes, 8 – 12 strips were cut from each sample. The strips were then bent back and forth four times to see if any voids appeared or if separation occurred. Any strips with defects outside the acceptable range constituted a failure of the test.

Figure 3: Visualization of the Fusion Evaluation Test as per 9.4.3 of ASTM F1055-13



Certain points of interest based on identified fusion anomalies in the NDT results were chosen to be analyzed via FET, along with randomly chosen points which passed the NDT assessments. The performance of the technology's detection rate was then determined using the correlation between the NDT analysis and destructive tests.

Results

Table 1 shows the initial results of the validation testing on 2” electrofusion couplings. Three joints were made for each preparation method, analyzed with the NDT technology and given an overall rating of pass or fail, and then destructively tested using FET. The technology proved to have consistent detection with good joints and defects that changed the shape of the fusion zone. Water contamination and over-scraping both produced voids, while under-insertion caused material to flow out of the fusion zone. The NDT results were fairly consistent with interrupted and mud contamination methods but failed to detect when the pipe was not scraped before fusion. The first validation test resulted in an overall accuracy of 75%.

Table 1: Results of Validation Testing

Prep Method		Good Joint	Water Cont.	Under Insertion	Over-Scraped	Interrupted Fusion	Mud Cont.	No Scrape/ Oxidized
Joint	**Test**	3/3	3/3	3/3	3/3	2/3	2/3	0/3
1	**NDT**	Pass	Fail	Fail	Fail	Fail	Pass	Pass
	FET	Pass	Fail	Fail	Fail	Pass	Fail	Fail
2	**NDT**	Pass	Fail	Fail	Fail	Fail	Fail	Pass
	FET	Pass	Fail	Fail	Fail	Fail	Fail	Fail
3	**NDT**	Pass	Fail	Fail	Fail	Fail	Fail	Pass
	FET	Pass	Fail	Fail	Fail	Fail	Fail	Fail

As the results presented in Table 1 show a lack of capability in detecting joints that have not been scraped, further improvements were made to the technology to better detect this defect. A new method of analyzing the ultrasonic signal was established and additional testing was completed to validate this methodology. Six additional 2” electrofusion coupling samples were created for three methods of preparation: good, mud contamination and no scraping. These samples were created in a blind fashion to eliminate the effect of bias. **Table 2** shows the results of the blind test with the advancements to the technology.

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Table 2: Results of Validation Testing with Advancements to Technology

Prep Method		Good Joint *	Water Cont.	Under Insertion	Over-Scraped	Interrupted Fusion	Mud Cont.*	No Scrape/ Oxidized*
Joint	Test	6/6	3/3	3/3	3/3	2/3	5/6	5/6
1	NDT	Pass	Fail	Fail	Fail	Fail	Pass	Pass
	FET	Pass	Fail	Fail	Fail	Pass	Fail	Fail
2	NDT	Pass	Fail	Fail	Fail	Fail	Fail	Fail
	FET	Pass	Fail	Fail	Fail	Fail	Fail	Fail
3	NDT	Pass	Fail	Fail	Fail	Fail	Fail	Fail
	FET	Pass	Fail	Fail	Fail	Fail	Fail	Fail
4	NDT	Pass					Fail	Fail
	FET	Pass					Fail	Fail
5	NDT	Pass					Fail	Fail
	FET	Pass					Fail	Fail
6	NDT	Pass					Fail	Fail
	FET	Pass					Fail	Fail

** Data from additional blind test*

With this advancement, the NDT technology becomes consistently accurate at detecting all defects. Combining the data from both validation tests, the overall accuracy is increased to 90%.

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Ongoing Development

JANA has several projects currently ongoing to further the development of the NDT technology.

Tapping Tees

In the North American gas industry, electrofusion tapping tees are frequently used. Research and development is in progress to adapt the technology for use with these tees. JANA has partnered with a gas distribution utility to pilot the technology on tapping tees. In addition, JANA will be conducting a similar study to the one done with 2" couplings, where a range of defects will be introduced into the joint and the detection rates will be determined.

Blind Trial

JANA has initiated a Blind Trial with eight North American gas distribution companies. Participating companies provided JANA coupling and tapping tee joints from multiple manufactures, ranging in size from 2"to 8". As is the nature of a Blind Trial, the supplied joints were prepared with possible defects in the joints, unknown to JANA. The objective of the Blind Trial is to ascertain the quality of each joint without any prior knowledge of the preparation of the joint. JANA has completed the NDT analysis on all 26 blind samples and is awaiting confirmation from the participating companies. This trial will enable quick development of the technology to be used with a wide range of couplings used in North America. Upon successful outcome, it will also further the overall validation of the technology.

Field Trials

JANA has arranged eight weeks of field trials with a US gas distribution company, at two different field locations, to determine how the technology will be applied in the field. The objective of the Field Trials is to determine what improvements need to be made to the technology to ensure the delivery of a functional product that can withstand field conditions.

Conclusion

A new ultrasonic NDT technology has been developed that is capable of consistently detecting defects in electrofusion joints. JANA has successfully adapted the technology to be used with 2" electrofusion joints through a validation methodology whereby the technology had a detection rate of 90%. Blind Trials and Field Trials are in progress to validate the technology on tapping tees, broaden the technology’s capabilities to include multiple sizes and manufacturers of joints and ready the technology for field use.

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