Elastomeric Wedges for Pulse-Echo Phased-Array on HDPE Butt Fusion Joints

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Abstract
Innovative development in polymer processing has allowed the design of small footprint phased array probe wedges for use on HDPE (high density polyethylene) butt fusion joints. These wedges have been used to demonstrate good sensitivity and steering capabilities in HDPE. Previous limitations due to internal wedge reflections have been reduced. Scan results on butt fusion joints illustrate the degree of steering available and analysis difficulties that are intrinsic due to the geometric shape of the butt fusion joint. Although intended primarily for use on HDPE, a demonstration of its application to standard metal materials is provided.

Keywords: phased-array, ultrasonic, HDPE butt fusion joints, ASTM E3044

1. Introduction

Due to its relative strength, low weight and low costs, high density polyethylene (HDPE) has been gaining popularity as a replacement for steel pipe. The butt-fusion joining technique used with HDPE has presented new NDT challenges. Ultrasonic techniques are ideally suited to these inspections; however, the relatively low acoustic velocity of HDPE results in a negative refraction for most of the standard refracting wedge materials. Membrane wedges filled with water [1, 2)] or commercially available wedges with a water-cavity with constant water delivery have been used in some applications; however, the membrane wedges are extremely large. When using the water-gap option it may suffer loss of water-column when working on inclined, rough or overhead surfaces and may also suffer from accumulating air bubbles. Water membrane options can also suffer from air-bubble accumulation and risk loss of couplant due to the normal wear that occurs when using a retaining membrane.

Time of Flight Diffraction (TOFD) has been readily adapted to the HDPE application and much smaller wedges can be configured using water cavities or low velocity polymers [3].
As convenient as TOFD is for examining HDPE butt-fusion joints, pulse-echo phased-array provides some advantages including not suffering from dead-zones on the near and far surfaces.

In 2017 a low velocity wedge design was configured for a small footprint phased-array probe (Olympus 5L16 A10) [4]. This was demonstrated on blocks of HDPE of various velocities and shown to be an effective means of detecting the tip diffracted signals from flat bottom holes (FBHs). At that time, there was no effective means of eliminating internal wedge echoes so the thickness HDPE that could be examined was limited.

Recently, Innovation Polymers (http://www.innovationpolymers.ca/) has developed a suitable damping material and a processing technique that allows the damping material to be bonded to the low acoustic velocity wedge material (Aqualink^{TM}). The result is a compact wedge design that has proven effective on butt fusion joints.

The damping design innovations have been used to produce wedges for several off-the shelf phased-array probes.

This paper describes the wedge design and then illustrates the application of sectorial scans on small diameter thin wall butt-fusion joints with machined targets. Potential application of the design to metals is also considered.

2. Design of Wedge

In the initial design of the phased-array wedge for HDPE applications [4] a forward slope was used along with a bevelled reflecting surface. This design helped, but still suffered from a standing wave signal due to the internal wedge reflections. This limited the soundpath distance in HDPE to about 40mm.

Use of a serrated mating edge on the front surface failed to increase scatter sufficiently. Attempts to glue a separate damping material to the wedge resulted in a hardened interface at the glue joint that was in itself a source of reflection, not transmission.

Eventually, a damping material was developed in which metal particles were incorporated and had similar melting and flow properties to Aqualink^{TM} (one of the low acoustic velocity materials developed in Innovation Polymers). A multi-step process was then used to fuse the damping and wedge materials in a common wedge-holder.

This integral damping nose plus the internal forward slope provides an effective elimination of unwanted wedge echoes. Since the materials are elastomeric (soft and rubbery) it is not possible to drill and tap holes in the wedge so as to mount the probe on the wedge. Instead, the wedge must be formed in a separate holder. The three components; wedge holder, refracting wedge and damping material, are then moulded in a further process and the finished product provides a product that minimises internal wedge echoes.

Figure 1 illustrates the overall design concepts of the phased-array pulse-echo wedge and holder.

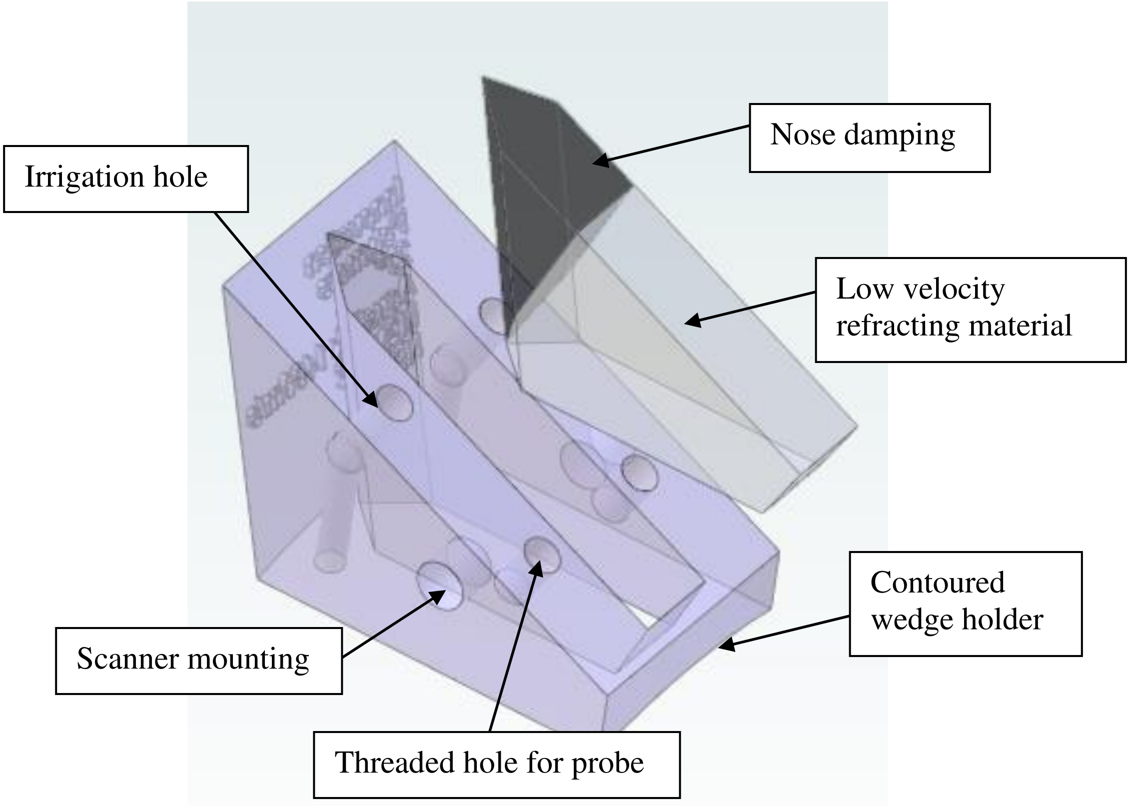

Figure 1 Integral Wedge and holder for pulse-echo phased-array

3. Calibration and Scanning using FBH targets

ASTM E3044 [5] describes a standard practice for ultrasonic testing of HDPE butt-fusion joints using both TOFD and phased-array ultrasonic techniques. This standard specifies that sensitivity be established using a minimum of three 3mm diameter FBHs and two square notches in a section of HDPE pipe. One of the FBHs is to be located at the mid-wall and the other two are to be positioned with 2mm ligaments to the inside and outside surfaces. Sensitivity is set so that the response from the tip diffracted signals from the FBHs is 40% full screen height for the weakest of the target responses.

ASTM allows that the section of pipe used for the reference targets be without a butt-fusion joint. The absence of a weld cap in the calibration standard greatly simplifies interpretation by having no interfering geometry to complicate analysis. This absence of weld caps is convenient for setting sensitivity but does not provide any indication of the challenges associated with the unique geometry in the HDPE butt fusion joint.

In order to both illustrate the sensitivity setting and the difficulties in analysis that are associated with the weld-cap geometry, two butt-fused samples were prepared with notch and FBH targets.

The samples used had nominal 12.5mm wall thickness and diameter was NPS 6 inch pipe.

The first sample was made with 3 flat bottom holes drilled to the middle of the fusion line. The ASTM-style surface notches were not included in the sample. Flat bottom holes were 3mm diameter and drilled 3mm, 6.25mm and 9mm from the outside surface. This provided a ligament of 1.5mm to the outside surface and 2mm to the inside.

The second sample had 4 flat bottom holes drilled to the middle of the fusion line; however, they were only 2mm diameter. These were centred 2, 4, 8 and 11mm from the outside surface. In addition to the FBHs, the sample with the 4 FBHs also had a slot milled in the middle of the cap-fusion positions to a depth of approximately 1mm below the surface of the pipe on the inside and outside surfaces. Another slot was made at the middle of the fusion line on the inside surface but was much deeper (about 4mm from the inside pipe surface).

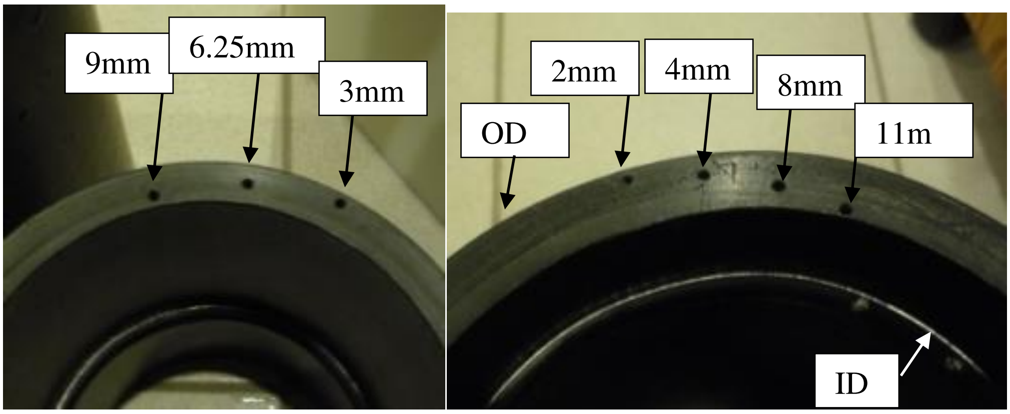

Figure 2 Targets in HDPE butt-fusion jointed pipe

These samples were scanned with an Olympus 5L32 A11probe on a wedge as illustrated in Figure 1. The refracting material was Aqualink^{TM} (Velocity = 1490m/s).

An S-scan display and Merged Side View is extracted from the scan of the 3mm FBH S-Scan results and provided as Figure 3. These figures illustrate the difficulty for analysis that occurs when large weld caps are present. In order to carry out effective analysis, the data is merged and then projection gates are used to limit the volume analysed. Careful gate placement is used to avoid the large geometry signals from both the near and far side cap signals.

Figure 3 indicates the origin of the signals in the S-scan at the location of the 3mm diameter FBH with a 2mm ligament from the inside surface. The projection gates in the S-scan are located at 36.8mm and 45.1mm on the index axis. In order to completely avoid the strong root-geometry signal the projection gate at 45.1mm would have to be moved to 41mm. Figure 3 includes an outline of the weld cap profile to help understand the origins of the signals.

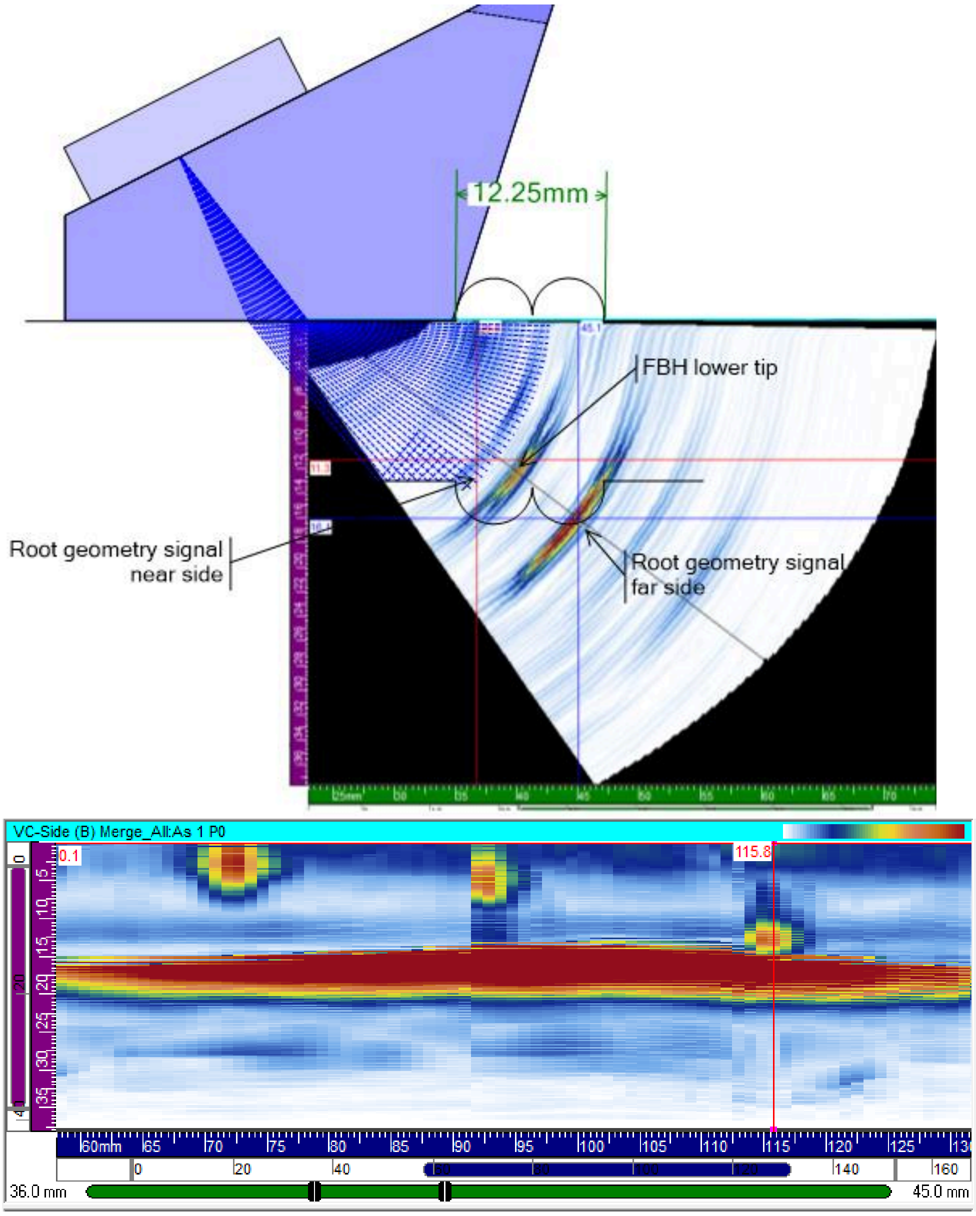

Figure 3 S-scan and volume corrected Side view of 3mm FBHs

It should be noted that it was possible to generate a sectorial scan from 35° to 89° in 1° increments. This allows good coverage of the full joint volume without relying on a reflection from the inside surface. This is particularly useful when considering the high attenuation associate with HDPE.

Ability to provide sensitivity at the near surface with the high angles obtained with the elastomeric wedge can be seen from the Merged Volumetric Side view of the second sample as shown in Figure 4. Note that in order to avoid most of the geometric signals the projection gate is used to limit analysis between 38mm to 45mm on the index axis. This is only about 3.5mm either side of the middle of the fusion zone.

Table 1 summarises the indications seen along the scan axis in Figure 4.

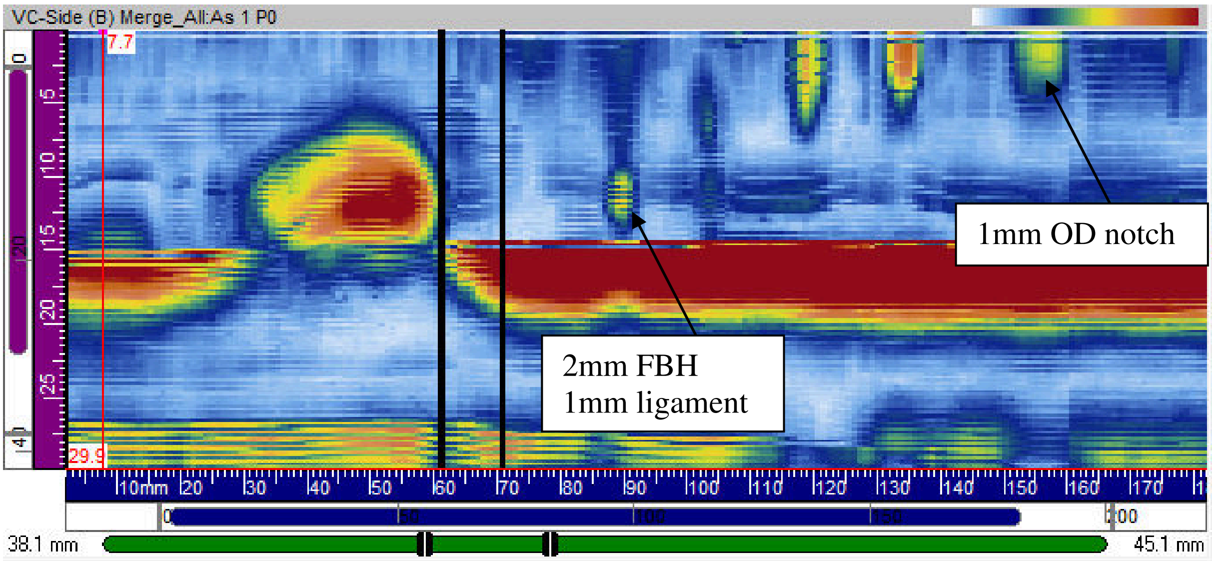

Figure 4 Merged Volumetric Side View Sample 2

Table 1 Sample 2 Indication Identification from Figure 2

Indication	Identification	Scan Axis Coordinate	Amplitude	Depth from outside surface
1	ID notch	45mm	100%+	8mm
2	2 FBH	90mm	40%	11mm (1mm ligament)
3	2 FBH	103mm	68%	8mm
4	2 FBH	119mm	70%	4mm
5	2 FBH	134mm	90%	2mm (1mm ligament)
6	OD notch	156mm	58%	1mm

The weakest FBH diffraction signal was set to 40%. Since the path variation from the inside to outside surface targets was only about 6mm, no TCG was applied.

As a result of the sensitivity using the direct path with high angles for the near surface targets, there was no need to employ any analysis in the second half skip of the lower angle beams. This is especially important in the thin wall joints where the beams are very likely to be mis-directed by interaction with the inside weld cap.

Civa analysis utilities can be used to import the scan data and plot the flaw locations on an extruded 2D figure. Figure 5 shows the Front View Section of the collected data in Civa and the Font and Side views of the 3D View with the flaws plotted using the Segmentation features in the analysis tools.

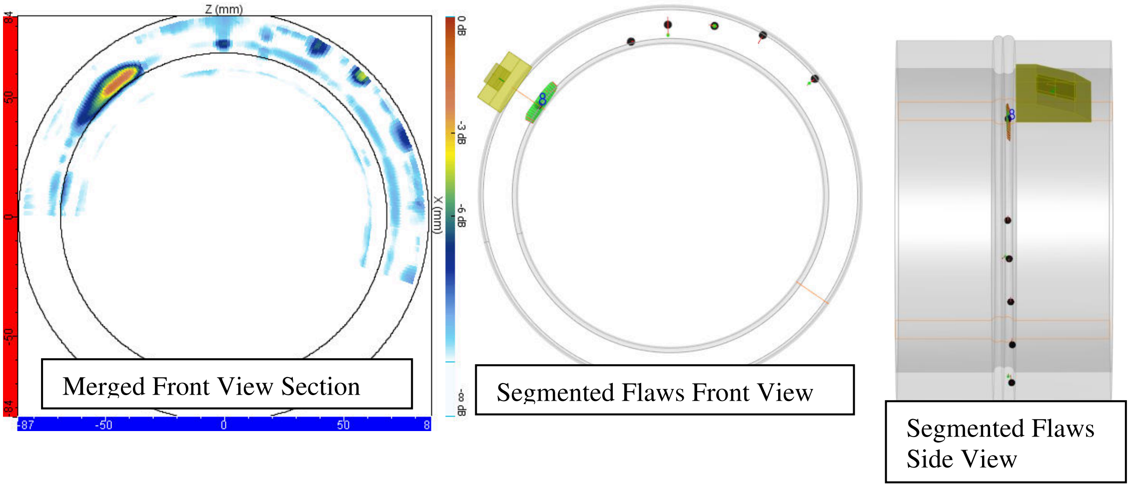

Figure 5 Civa Data Analysis

4. Use on Metals

Although primarily designed to be used on HDPE butt-fusion joints, the Aqualink^{TM} wedge can be applied to metals. Figure 5 illustrates the 5L32 A11 probe used on the elastomeric wedge with 24 elements activated and focussed at 25mm half-path. Using a 35-70° S-scan, the 1mm diameter side drilled holes at 25mm radius in the "Harfang" block are well resolved. This is the same probe and wedge combination as was used on the HDPE samples with only the delay laws changed for the steel velocity.

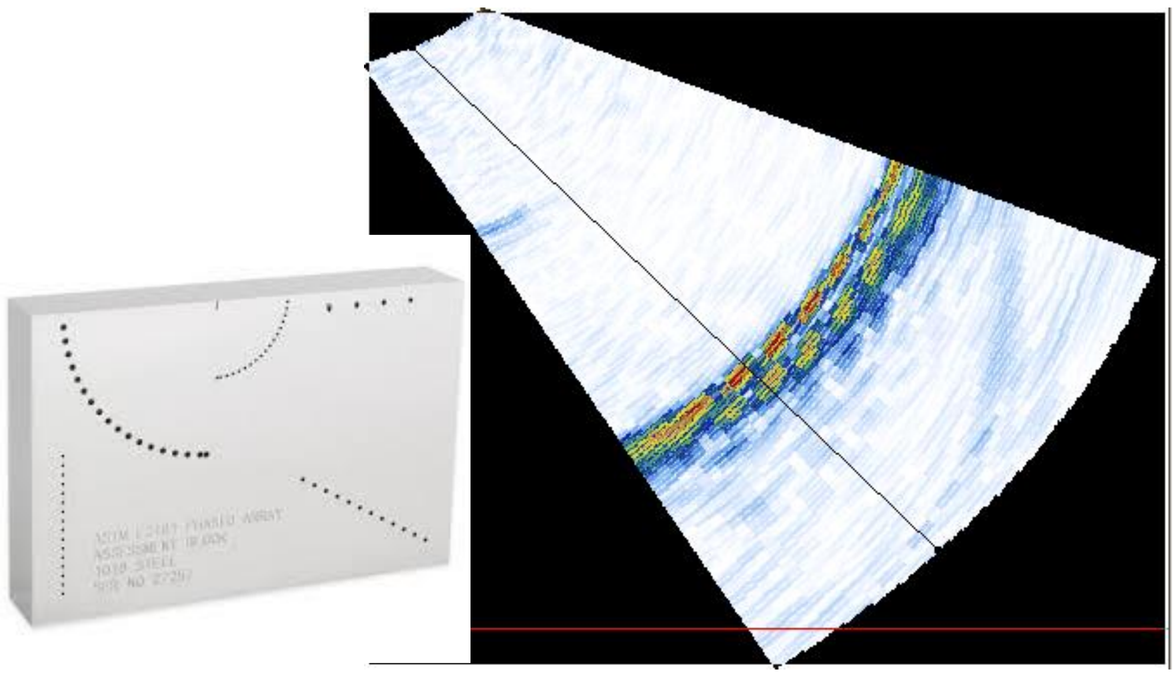

Figure 5 Harfang 25mm radius array of 1mm diameter SHDs with Aqualink^{TM} wedge

5. Conclusions

Design of a low velocity wedge material with integral nose-damping material has improved the range and SNR (signal to noise ratio) possible when testing HDPE butt-fusion joints with phased-array sectorial scanning techniques. The same design of elastomeric wedge can be used on metal with suitable protection of the soft wedge surface.

At present, a single incident angle of 27° from Aqualink^{TM} is used in the wedge design. With HDPE velocities ranging from 2100m/s to about 2600m/s [6], this provides a natural refracted angle from 40° to 53° depending on the formulation and processing of the HDPE being tested. Weld holders are machined with suitable curvatures specific to nominal pipe size (NPS) dimensions. Because elastomeric materials are not possible to shape by machining, moulds are made to form the wedge contact surfaces to the required surface curvatures using specially designed moulds. Wedge holders suitable for M2M G1 and G2 style probes and Olympus A10 and A11 style probes have been fabricated; styles will be considered.

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