

Plastic Fantastic? - An NDE Inspection Solution for HDPE Butt Welds

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Abstract

This paper presents a technique that has been developed for EDF Energy to detect butt weld defects in HDPE pipework using phased array ultrasonics. The technique uses a customized wedge to support a sound velocity difference that can generate forward angle beams within the low velocity and high attenuation material properties of HDPE.

Test blocks have been manufactured with a variety of subsurface implanted targets. All these targets have been detected with a signal to noise ratio of greater than 12 dB. Additionally, the ability to resolve target edges is demonstrated allowing measurement of through wall defect size.

The capability of detecting lack of fusion defects greater than 6 mm circumferential length by 2 mm through wall within HDPE pipework using phased array technology is presented together with the challenges overcome during development of the probe and manufacture of representative test blocks.

Keywords: High Density Polyethylene (HDPE), phased array

1.0 Introduction

High Density Polyethylene (HDPE) is an alternative material being adopted for the replacement of cast iron tertiary cooling pipework currently instated at nuclear power plants [1, 2]. The attractiveness of HDPE pipework is related to the long-term structural integrity benefits that it has to offer because it does not corrode, is flexible, lightweight and a cost effective replacement for metal pipes.

HDPE butt welds are manufactured in four stages: heating, heat soaking, heater plate removal and joining-cooling [3, 4]. The heating stage involves the two prepared pipe sections of HDPE being pressed against a heater plate under a specific pressure and being held there for a specific time (heat soaking). Thereafter, the heater plate is removed and the two ends are aligned exactly and brought together. The joining-cooling process involves the compression of the two faces together and being held for a specified duration in order to fuse the two ends. The excess material squeezed out during the butt fusion force forms a bead on the inner and outer surface of the weld leaving virtually no heat affected zone in the weld. There can be a requirement remove the weld bead to be removed from both surfaces to prevent growth and blockages of invertebrates or plants. This often results in an irregular and rough weld profile.

Installation and joining of HDPE pipework sections happens in-situ where environmental conditions may introduce impurities such as grease, dust, dirt and sand to both the heater plate and pipe ends. This type of contamination can lead to defects in the butt fusion weld. The size of the air pocket created by the contaminants can produce a Lack of Fusion (LoF) where there is no bond or a partial bond between the faces of the

sections. Generally it is considered that any LoF present will occur perpendicular to the radial-axial plane i.e. 0° tilt. Kissing bonds or cold joints can occur when the contact that is made is not sufficient to form bonds capable of transmitting shear stress resulting in a lack of strength [5]. This can be caused by several factors including excessively long heater plate removal time, inadequate heat to the end of the HDPE sections or misalignment of the two ends.

Current quality assurance systems in place include approved personnel, monitoring of welding conditions and visual inspection. Further tests include hydrostatically testing spools of pipe, cutting a sample of weld and destructive testing through tensile/ bend tests.

It has been documented that the Time Of Flight Diffraction (TOFD) technique has the ability to detect defects in the HDPE material [6], however this technique has limitations. The deployment of TOFD requires access from both sides of the weld and a level surface. It is required that the technique shall be applicable to pipe to pipe welds and pipe to fitting welds. Fittings prevent access to one side of the weld and therefore all the joints cannot be inspected with TOFD. Phased array and microwave inspection of HDPE materials have been reported elsewhere [1-3, 5-8].

This paper presents a phased array inspection solution for detection and sizing of LoF-type defects in HDPE weld specimens.

2.0 Inspection Solution

2.1.1 Inspection Method

HDPE is a material with high density and high attenuation values. Shear waves are not supported in HDPE due to the material properties and hence longitudinal waves are the only possible inspection mode.

The longitudinal velocity of sound in HDPE is approximately 2150 m/s. The velocity can have relatively large variations in depending on the specific batch, potentially varying on material either side of the weld. Furthermore, it is believed that there are also minor fluctuations in velocity that are dependent on the angle of the sound travelling through the crystalline structure [3]. HDPE pipework is very attenuative (0.3 dB/mm using a 2.25 MHz probe) and therefore acquisition was limited to the shortest inspection range possible, in practise this being half-skip.

During the test trial stage of the development, an 'off the shelf' 32 element 2.25 MHz phased array probe in pulse-echo mode with a sweep of 35° up to 89° has been used to produce a volumetric inspection of the weld and Heat Affected Zone (HAZ). Data was collected using Zetec's Dynaray system which was in turn driven using Ultravision 3 software via a laptop. The technique utilised water as a wedge medium resulting in a sound velocity difference that can generate forward angle beams within the HDPE pipework.

2.1.2 Bespoke Ultrasonic Probe Wedge

It has been widely reported that the challenge presented by HDPE is to find a material with a slower velocity in order to generate forward steering angles, as determined with Snell's Law, but to also have low attenuation [5]. Therefore, to generate forward steering angles, a wedge medium with a slower velocity than HDPE is needed.

Conventional Perspex (2740 m/s) and Rexolite (2350 m/s) shoes are inappropriate as the change in velocity is not suitable to generate forward looking angle beams. A phased array system with two low frequency probes and two wedges; a gel wedge (slower velocity to generate higher angle beams) in combination with a Rexolite wedge is commercially available [1] for inspection of HDPE pipework. Water has been used as a stand-off but the wedge designs are basic and have not been developed and optimised for stand-alone industrial use on site applications [8].

In order to produce a useful refracted angle within the HDPE, a bespoke water wedge has been designed. The probe is housed in the wedge at an angle of 21° in a custom-built water-filled acoustic stand-off secured with a 0.6 mm conformable membrane interface. An early development design is shown in **Figure 1**. Non-return valves prevent water loss and machined channels remove any air build up on the array face and membrane. The membrane pocket at the front of the housing contains air to act as a spring for the membrane interface. The membrane retains the water at the face of the probe and does not affect the intended frequency propagated into the material i.e. the rubber is acoustically transparent at 2.25 MHz. A wear plate and adjustable screws on the bottom of the holder are used to avoid deterioration of the membrane and provide stability on the component surface.

Longitudinal waves are generated at the membrane-HDPE interface to allow refraction at 35° up to 89° for half-skip inspection. In practice, the array holder can be used in any orientation and is therefore versatile for inspection of all welds geometries and locations.

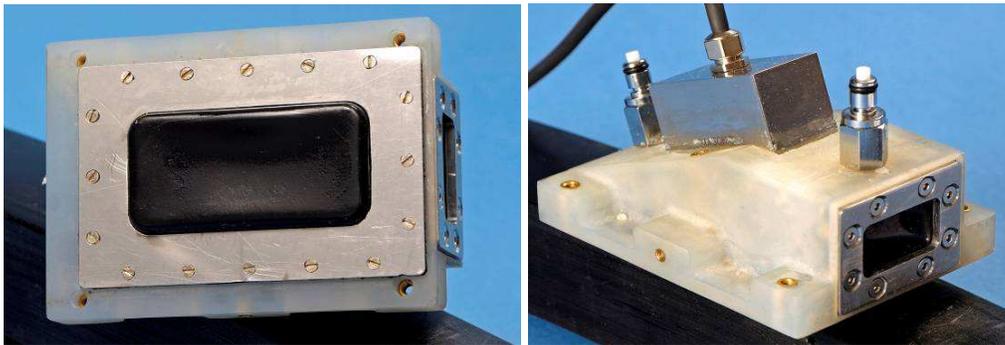


Figure 1. (Left) Base of water wedge (Right) Side-view of water wedge

3.0 Manufacture of Test Specimens

To evaluate the inspection capability of the phased array water wedge system, a number of sample welds were designed and manufactured. The test specimens (450 mm diameter and 38 mm wall thickness PE100 to BS EN 12201) were constructed by EDF Energy's chosen contractor.

In addition to this, a calibration block was manufactured using HDPE material. A 40mm thick block manufactured from the pipe material containing Ø3 mm side-drilled holes and geometric reflectors was used to demonstrate positional accuracy and calibrate the sensitivity (**Figure 2**). Side-drilled holes are a preferred target due to the difficulty in accurately machining flat bottom holes.

Test specimens were designed to contain variable sizes of small stainless steel oval inserts to represent defects present in the weld (see **Figure 2**). The supplied shims were all 0.2 mm thick which is approximately $\frac{1}{4}$ of a wavelength. It is considered that the stainless steel insert conservatively represent LoF because they represent a bonded implant where lack of fusion is effectively air with a greater acoustic impedance difference. Occasionally it is suspected that the plastic did not bond to the insert in this case the lack of fusion is real. The bottom edge of the discs can only be detected via diffraction whereas the top edge could occasionally be detected via pulse echo due to reflection from the lack of fusion of the plastic to the insert. The oval edge ensures that the diffracted signal is small and representative of a real irregular defect. The design of the test piece and stainless steel inserts were supplied to the contractor for construction.



Figure 2. (Left) Phased array in water wedge on calibration block with test specimen and (Right) weld cap removal surface finish

The manufacturing of the test welds presented their own challenges as the stainless steel inserts are free to move as the HDPE becomes molten during fusion. This resulted in reflectors not being in the as designed locations and in some cases being pushed completely out of the material and into the weld bead. From test specimen manufacture information, in a real-life situation there is a tendency for impurities that are not squeezed out into the weld bead have a tendency to be embedded near the outer and inner third of the pipe during butt fusion welding. Other development work has used PTFE strips as ultrasonic targets. It was found that thin PTFE will deform during the welding process and the final position and shape of the target is an unknown without

destructive examination. For this reason PTFE was discounted as a means of implanting a realistic but known defect.

Despite the positioning difficulties and uncertainties, it is known that the target sizes are 2 mm x 6 mm, 3 mm x 9 mm and 4 mm x 12 mm as the size and shape of the stainless targets could not change during welding. Radiographic images were taken of each test piece so that the appropriate target sizes could be identified. In addition, radiography was used to determine the approximate locations and depths of each reflector. Three test pieces were produced all to the same design but each piece was unique due to manufacturing variations, allowing for a comprehensive set of targets to be examined.

The surface finish (**Figure 2**) following weld cap removal imposed some inspection restrictions; an inability to scan up to and over the weld and very rough surface finish resulting in spurious signals.

4.0 Inspection Results

All trials included in this paper have been performed with the material at ambient temperature. It is understood that the temperature of HDPE material has an effect on its sound velocity [5]. Other studies have shown that a cooling time of at least 2 hours will be required for HDPE pipework of this section thickness to reach suitable inspection temperature. The cooling time will depend upon the environment in which the weld is made. It should be noted that this paper does not examine cooling time.

All but three targets within the inspection zone were clearly detected with a signal to noise ratio of 12 dB or better. These exceptions were:

1. Two targets that protrude out of the inner and outer surfaces where the weld caps have been removed leaving a rough surface.
2. A signal from a target that lies within the noise band of the wedge resulting in the inability to differentiate between the response and the standing echo.

Near surface targets produced a specular response due to the low incident angle which the beam strikes the target (**Figure 3**). For those targets at a greater depth, and therefore seen at higher incidence, tip diffraction is the dominant signal source from the implanted targets (**Figure 4**). From figures 3 and 4 it can be seen that the chosen targets were oval. Unlike conventional welding where the weld runs are laid down essentially parallel to the outside diameter (OD) with consequential weld defects being parallel to the OD of the pipe, these welding defects are generally created via contamination. The orientation is perpendicular to the through wall direction but the defect edges can be at any orientation with respect to the outside surface. Diffraction amplitudes are particularly variable with respect to rotation relative to the scanning surface. This is a further reason why TOFD is not necessarily the first choice for inspection and why particular attention was taken in the choice of oval defect targets.

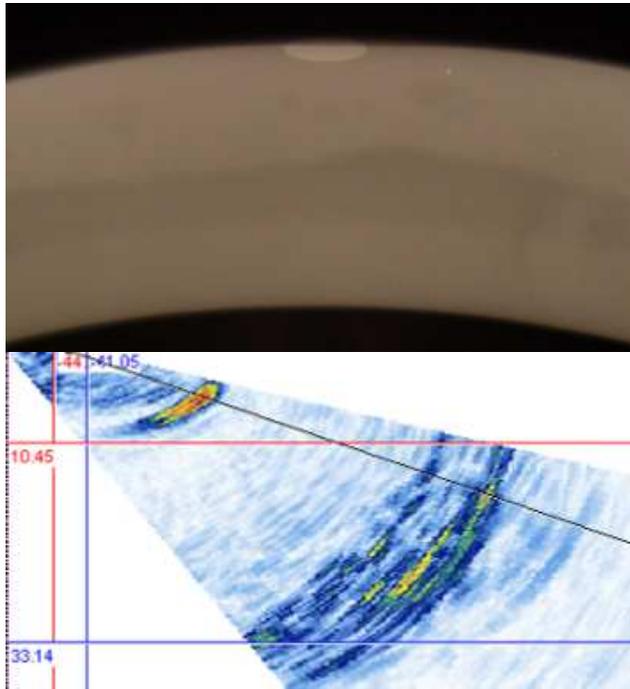


Figure 3. (Top) Radiograph showing a near surface reflector within the pie and (bottom) its specular response

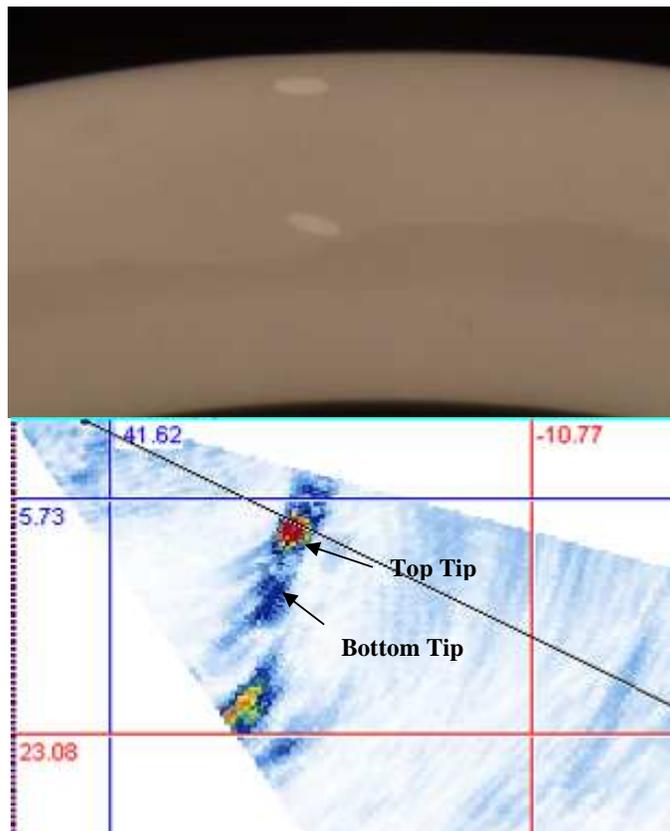


Figure 4. (Top) Radiograph of two targets embedded within the test block (Bottom) Edges of target resolved using tip diffraction.

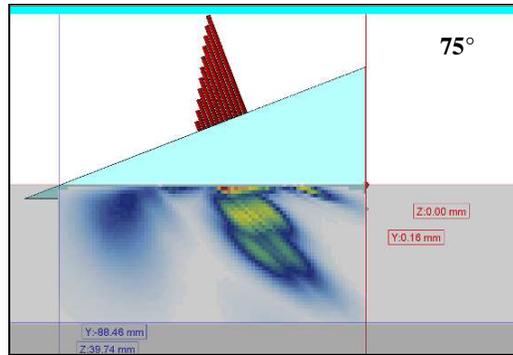


Figure 5. Beam modelling of angled beam sweep with current set-up of phased array probe and wedge

5.0 Conclusions

An inspection technique to examine HDPE butt welds using phased array technology has been developed with a customised water membrane interface housing to accommodate for the slow velocity material property of HDPE.

HDPE pipe welds have been supplied with a variety of implanted targets. Those targets within the weld volume that have been correctly inserted and do not protrude from inner or outer surfaces have been detected with a signal to noise ratio of greater than 12 dB. In addition, the ability to resolve target edges was demonstrated allowing measurement of through wall defect size.

The capability of detecting lack of fusion defects greater than 6 mm circumferential length by 2 mm through wall within HDPE pipework using phased array technology has been demonstrated.

6.0 Further Work

Further work is under way to develop this technique into a deployable inspection solution. The installed pipe work may be in trenches during the inspection and so an in-situ manipulator will be required. This ongoing work includes:

- Optimise probe design - specific to water/ HDPE interfaces in order to minimise grating lobes.
- Second generation of water wedge to house new design of probe
- Integrate probe with a pipe inspection manipulator that will allow fully encoded 360° circumferential inspection
- Integrate with flaw detector system suitable for remote working and site environments.

In addition to this, further development work is required to fully assess the capability of the inspection system. Further test pieces will be produced to generate sufficient test data to produce a detailed technical justification for the inspection technique.

7.0 References

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