Proceedings of the 17th International Conference on Nuclear Engineering
ICONE17
July 12-16, 2009, Brussels, Belgium

ICONE17-75859

ULTRASONIC PHASED ARRAY EXAMINATION OF BUTT-FUSION JOINTS IN HIGH-DENSITY POLYETHYLENE

Caleb Frederick
Structural Integrity Associates, Inc

Allen Porter
Structural Integrity Associates, Inc

David Zimmerman
Duke Energy

Charlotte, North Carolina, U.S.A.

ABSTRACT

With the increasing use of High-Density Polyethylene (HDPE) piping for nuclear applications, nondestructive evaluation is an important tool for evaluation of the integrity in fused joints. This paper will discuss the method of using Ultrasonic Phased Array for inspecting Butt-Fusion (BF) joints in HDPE piping. The benefit of Phased Array is the ability to perform a volumetric inspection using multiple angles which greatly increases the probability of detection of defects, and allows the data to be analyzed using a representative 2-dimentional image of the joint [1]. It has been determined that successfully producing BF joints is highly dependent on environmental and mating-surface conditions. The primary defects of concern are lack-of-fusion (LOF), an area of the joint where there is no bond [2], cold fusion (CF), an area of partial bond, and inclusion. Phased Array has successfully demonstrated the ability of detecting and characterizing these defects using low frequency ultrasound. Factors addressed include joint location, wall thickness, material temperature, transducer wedge material, and manual vs. automated data acquisition.

1 INTRODUCTION

Metal is the ASME predominantly used material for piping and other pressure retaining components used in the nuclear industry. Although metal piping is historically the most commonly used piping material found in nuclear power plants, the metal piping used to transport water is prone to corrosion, fouling, and microbiological attack [3] which requires continual maintenance, repair, chemical treatment and replacement of degraded piping [4]. To eliminate the challenges associated with metal piping, the nuclear power industry is now selectively using High-Density Polyethylene (HDPE) piping for non-safety related applications and considering broader use of HDPE. HDPE piping is preferred as it does not rust, rot, corrode, tuberculate, or support biological growth [3]. In addition, the use of the HDPE piping in raw water applications ensures long term structural integrity and water flow reliability [3] with a minimum of maintenance. The applicable Construction Codes and later editions and addenda do not provide rules for the material, design, fabrication, installation, examination and testing of piping constructed with HDPE material [3]. Consequently, ASME Code Case N-755 was developed to provide requirements for nuclear power plant applications of HDPE. The Code Case requires visual inspections of the formed beads [3, 4]. Examination requirements for Code Case N-755 were developed to be consistent with ASME Section III Class 3 examination requirements that do not require volumetric examination of welds. However, volumetric examination could prove very valuable in obtaining regulatory acceptance for the first installations of Polyethylene piping in ASME Section III Class 3 applications. To date, the only example of this is Ameren Callaway plant in the U.S., which recently installed approximately 600 linear feet of 36-inch diameter buried HDPE piping in a safety-related application.

To ensure the absence of subsurface fusion problems, ultrasonic testing methods have been developed. Although time-of-flight diffraction (TOFD) methods have been used effectively for volumetric examination of HDPE butt welds, another promising technology is ultrasonic phased array which provides easy to interpret 2-dimensional images of the fusion zone and also provides the added benefit of discriminating between indications on the fusion line and those in the adjacent base material without additional scans. The following sections discuss the technical approach taken to examine HDPE piping welds up to 4 inches thick and the documented results on flawed samples including the detection of Cold Fusion.

2 INSPECTION OF HDPE PIPING:

High-Density Polyethylene presents certain challenges when developing a solution for volumetric inspection. Like all materials, sound propagation diminishes with increase in soundpath. However, HDPE diminishes propagation more rapidly than most materials with a ~18dB drop in amplitude response per inch. At higher temperatures, this material becomes even more difficult to penetrate due to its decreasing velocity, and also has an affect on the fusion process [3]. For this reason, the NRC considers temperature an essential variable. Inspecting HDPE piping with up to 4-inch (101.6 mm) wall thickness requires a balance between the ability to penetrate, while still sensitive enough to detect small flaws. Shear waves do not propagate in HDPE effectively due to wavelength, thus limiting inspection to longitudinal waves.

When using a Rexolite wedge (a common material for Phased Array wedges) there is little to no refraction taking place due to a nearly identical velocity as HDPE. So, the angle that is present in the wedge is the same as it will be in HDPE. This limits the sweep of angles that can be used in large part to the length of the wedge, which in-turn increases the soundpath. By limiting the sweep of angles into the specimen, this reduces the coverage of the fused joint.

The solution is to utilize a low frequency probe with wedge material velocity similar to that of the HDPE, to cover from just above mid-wall to the inside-diameter (ID) surface, and use a second probe of slightly higher frequency with wedge material much slower than that of HDPE in order to take advantage of refracted angles sweeping from just below mid-wall to near the outside-diameter (OD) surface. This provides an overlap of mid-wall coverage, with a combined coverage of the lower 97% of the fused joint.

Recommended field practice would be to perform automated scans, then investigate areas of concern manually. This provides one continuous scan (or can be broken into segments), with uniform probe positioning, while recording indication locations that are saved as permanent record.

Imaging is an additional benefit with Phased Array, as you can define different views prior to inspection which can be observed during "live" scanning, or defined during analysis after the data has been recorded. These additional views are B-Scan (side), C-Scan (top), and D-Scan (end), which can be displayed either "corrected" or "uncorrected" for the angle recorded [1].

Finally, joint inspections in HDPE piping using TOFD are currently limited to areas where feasible [3]. Therefore, joints in obtuse sections of pipe are limited to visual inspection along the ID and OD surfaces. Phased Array by comparison only requires access from one side of the joint at a time.

3 INSPECTION TECHNIQUE: 4 INCH (101.6 MM) WALL THICKNESS:

In developing this inspection technique, two low-frequency probes (one of which is slightly higher frequency than the other) are used to provide coverage of the fused joint. The joint is therefore broken into two zones. One probe providing an angular sweep from 0 - 50 degrees, while the second probe sweeps from 30 - 85 degrees. Figure 1 below shows a simulation of the coverage provided by each probe. Notice the overlap at mid-volume.

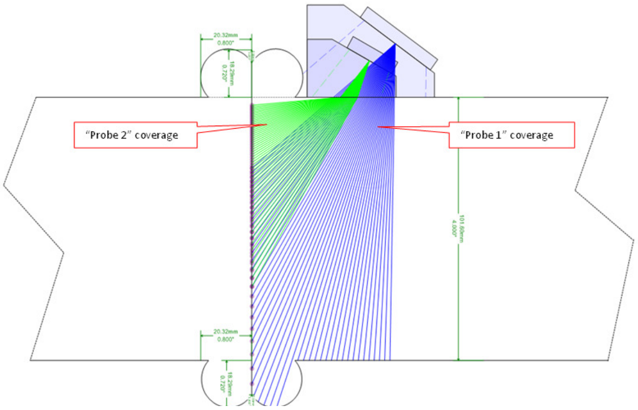

Figure 1. Cross-sectional view with beam coverage using two probes

As you can see, the probe covering the bottom ⅔ volume has no refraction, while the probe covering the top ⅔ (overlapping the middle ⅓) refracts due to the difference in longitudinal velocity of the wedge material and HDPE. This refraction was utilized to achieve maximum near-surface coverage at high angles.

Using these two probes, we have successfully achieved the balance of full penetration, while still sensitive enough to detect a 1/32 in. (0.8 mm) diameter reflector throughout the volume.

3.1. Description of 4 inch Wall Calibration Block:

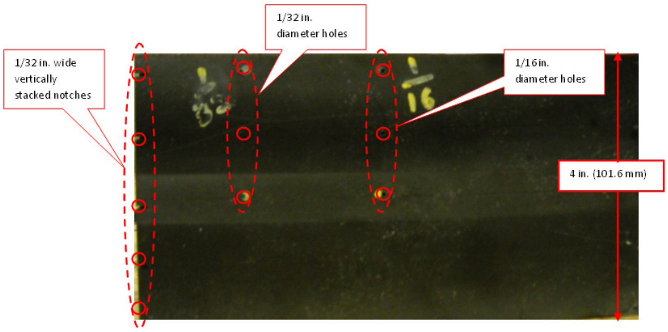

Figure 2. Calibration block for 4 in. wall thickness

3.2. Preliminary Test Results:

Figure 3 below is of the ultrasonic responses from the 1/32 in. vertically stacked notches on the end of the calibration block. Sensitivity level was established by setting the midwall notch to 80% Full Screen Height (FSH). This low-frequency probe used an angular sweep from 0 - 50 degrees. (See Probe 1 in Figure 1 above)

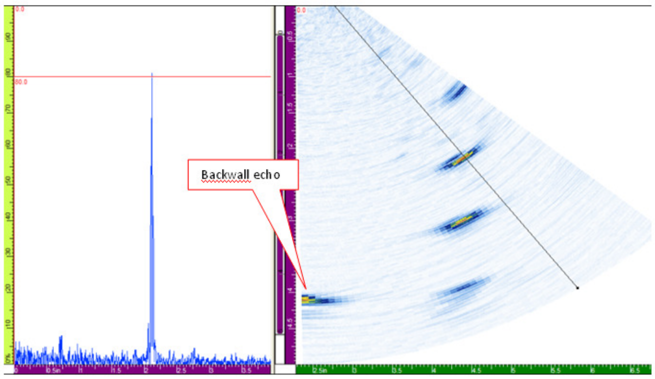

Figure 3. Ultrasonic responses from 1/32 in. vertically stacked notches

Figure 4 below is of the ultrasonic responses from the vertically stacked 1/16 in. (1.6 mm) diameter holes on the top half of the calibration block. Sensitivity level was established by setting the middle hole to 80% FSH. This slightly higher frequency probe used an angular sweep from 30 – 85 degrees. (See Probe 2 in Figure 1 above)

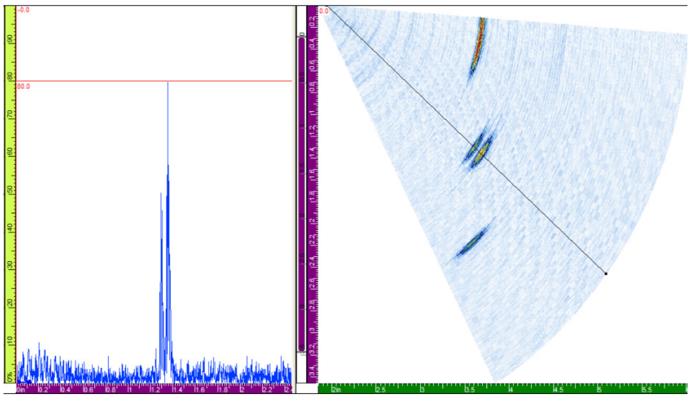

Figure 4. Ultrasonic responses from 1/16 in. diameter vertically stacked holes

Using the same probe as above, Figure 5 below are the ultrasonic responses from the vertically stacked 1/32 in. diameter holes on the top half of the calibration block. Sensitivity level was established by setting the middle hole to 80% FSH.

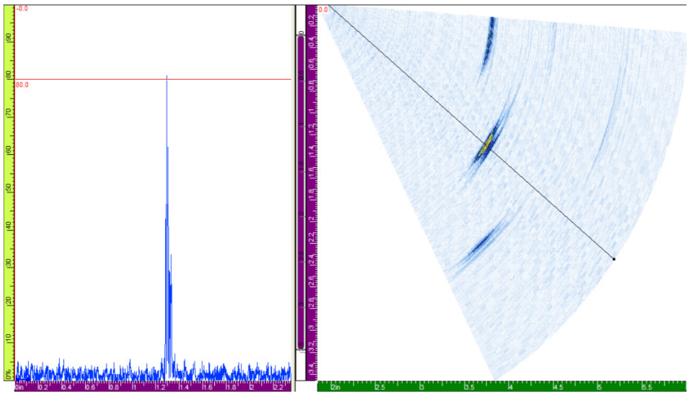

Figure 5. Ultrasonic responses from vertically stacked 1/32 in. diameter holes

Using Probe 1 with sensitivity level set using midwall 1/32 in. diameter hole, the same size reflector can be detected at the far-surface.

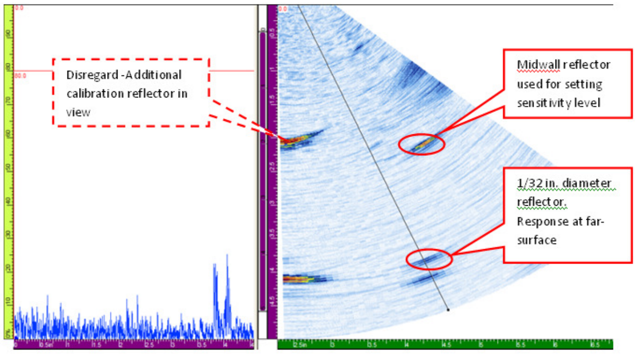

Figure 6. Detection of midwall and far-surface 1/32 in. diameter holes

4 INSPECTION TECHNIQUE: 0.67 INCH (17 MM) WALL THICKNESS:

Using Probe 2 in its original configuration applied to a much thinner specimen, this probe has the ability to penetrate to the ID surface, and is sensitive enough to detect a 1/32 in. diameter hole throughout the fusion. (See Figure 7 below)

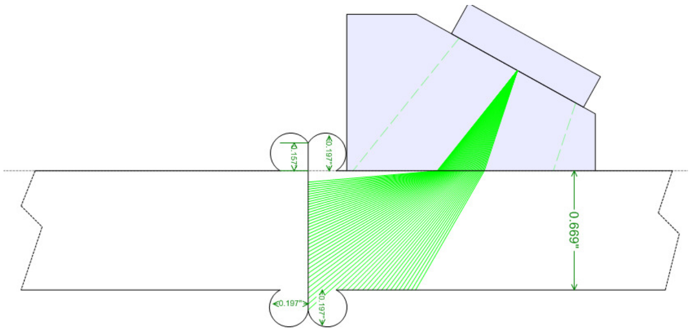

Figure 7. Cross-sectional view and beam coverage using one probe

4.1. Description of 0.67 inch Wall Calibration Block:

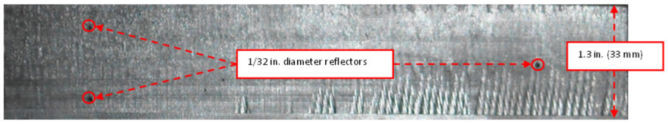

Figure 8. Calibration block for up to 1.3 in. wall thickness

Figure 9 below shows the established sensitivity level by using the 1/32 in diameter near-surface hole in the calibration block. (The near-surface hole was used because it is the same depth as midwall in the specimen).

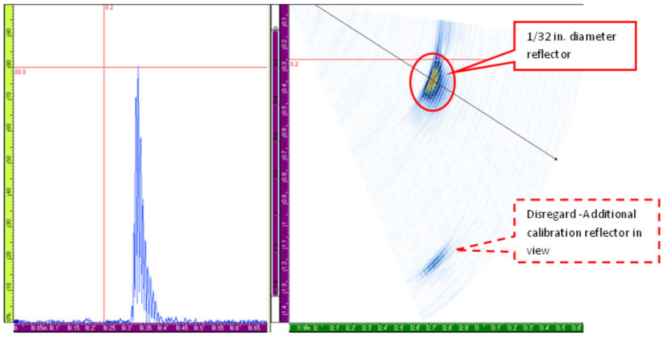

Figure 9. Sensitivity level established using near-surface 1/32 in. diameter hole

4.2. Preliminary Test Results:

Using the sensitivity level established as described in Figure 9, this appears to be a "good" component as there are only responses from the backwall and ID geometry. Notice there is no fusion line detected as the material is now contiguous throughout the fused joint. The ultrasonic results were later verified through destructive testing. (See Figure 10)

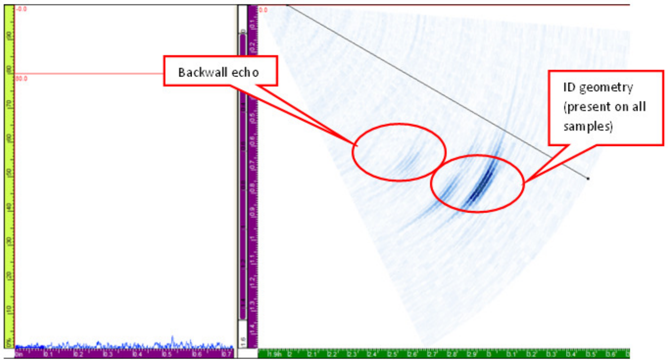

Figure 10. Backwall and ID geometry responses in a "good" joint

Figure 11 below is the destructive verification of the "good" joint shown in Figure 10.

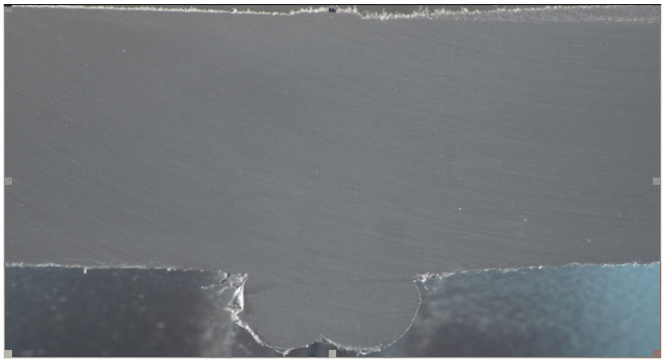

Figure 11. Cross-sectional view from destructive verification of "good" joint

By comparison, the joint shown in Figures 12 and 13, has the same backwall and ID geometry responses, but also Cold Fusion throughout the joint. Note: Cold Fusion has been verified by us only based on these two specimens. Additional testing is required to better understand levels of detectability of Cold Fusion.

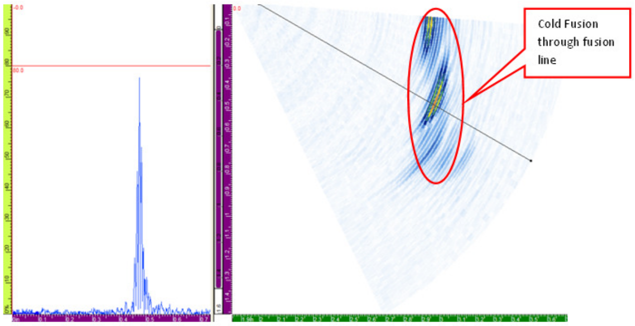

Figure 12. Cold Fusion in joint

Figure 13 below is the destructive verification of the "Bad" joint shown in Figure 12.

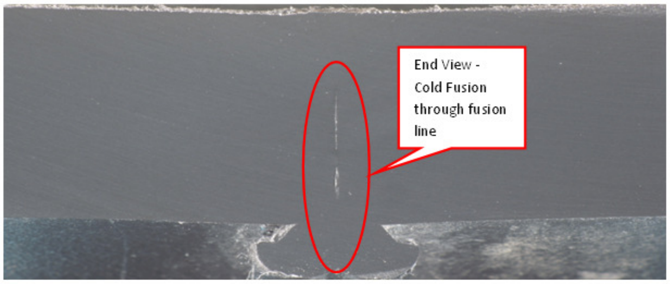

Figure 13. Cross-sectional view from destructive verification of Cold Fusion in joint

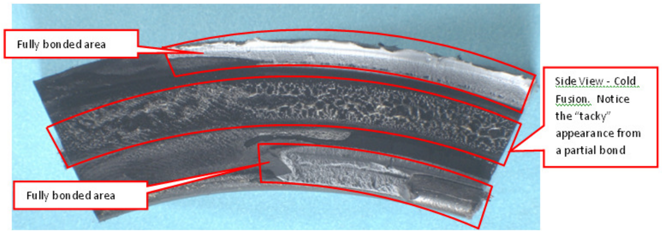

Figure 14. Side view of joint after destructive verification of Cold Fusion

CONCLUSION

Based on the specimens tested, Ultrasonic Phased Array has proven capable of detecting a 1/32 in. diameter hole throughout the fusion line, while providing a full 2-dimensional view of the fusion and adjacent base material. There has been much documented concern by both utilities and the Nuclear Regulatory Commission regarding the ability to detect Cold Fusion in HDPE. Through our limited testing, we have been able to detect, accurately interpret, and destructively verify Cold Fusion. Though additional testing is required, Phased Array has shown great potential in its ability to volumetrically inspect High Density Polyethylene piping.

REFERENCES

[1] Moles, M., Davis, M., Magruder, C., Ciorau, P., 2005, *Phased Array Technical Guidelines: Useful Formulas, Graphs, and Examples*, R/D Tech Corp., Quebec City, pp. 5 - 79.

[2] Crawford, S.L., Cumblidge, S.E., Doctor , S.R., Hall, T.E., Anderson, M.T., 2008, "Preliminary Assessment of NDE Methods on Inspection of HDPE Butt Fusion Piping Joints for Lack of Fusion," JCN N6398, Task 2D, Pacific Northwest National Laboratory, Richland, WA.

[3] Naujock, D., Basavaraju, C., 2008, "Safety Evaluation by the Office of Nuclear Reactor Regulation, Relief Request No. I3R-10, Third 10-Year Inservice Inspection Interval, Union Electric Company, Callaway Plant, Unit1," Docket No. 50-483, United States Nuclear Regulatory Commission, Washington, D.C.

[4] Naujock, D., Dasavaraju, C., 2008, "Safety Evaluation by the Office of Nuclear Reactor Regulation, Relief Request No. 06-CN-003, Catawba Nuclear Station, Units 1 and 2, Duke Energy Carolinas, LLC," Docket Nos. 50-413 and 50-414, United States Nuclear Regulatory Commission, Washington, D.C.