The e-Journal of Nondestructive Testing - ISSN 1435-4934 - www.ndt.net

Impedance Matching Polymers

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2021.04.15

Abstract
Acoustic impedance is a simple parameter to calculate and it is often used to get an impression for how well sound will move from one medium to another. Acoustic impedance matching is a term used to identify how well one material will allow a sound to move from one material to another. This paper provides simple visual illustrations of the effect of impedance matching.

Keywords: Polymers, ultrasonic, impedance, matching

1. Introduction

This paper provides a simple approach to understanding why acoustic impedance matching can be useful in ultrasonic testing. Acoustic impedance in industrial ultrasonic applications is usually the "specific" acoustic impedance. Specific acoustic impedance is given in units of pascal second per metre (Pa·s/m). This is also termed the rayl (named after Lord Rayleigh) and given the symbol Z. Z is calculated as the product of density times acoustic velocity. Standard units in the metric system for density are kilograms per cubic metre (kg/m^3) and velocity in the metric system is given in metres per second (m/s). This makes for a lot of zeros when quoting acoustic impedance so the common unit is the MegaRayl (MRayl or Mrayl).

Typical values of specific acoustic impedance for some materials are given in Table 1. Note, there can be variations from sample to sample so the values are merely representative.

Table 1 **Acoustic Impedance of Sample materials**

Material	Acoustic Impedance (MRayl)
Water	1.48
Alcohol	0.91
Glycerine	2.50
Steel	45.5
Aluminium	17.3
HDPE	2.30
Polymethylmethacrylate	3.21
Polycarbonate (Lexan™)	2.72
Polyetherimide (Ultem™)	3.13
Crosslinked polystyrene (Rexolite™)	3.73

The concepts of reflection and transmission coefficients are basic to the ultrasonic inspection process. These are determined for normal incidence using values of acoustic impedance as illustrated in Figure 1.

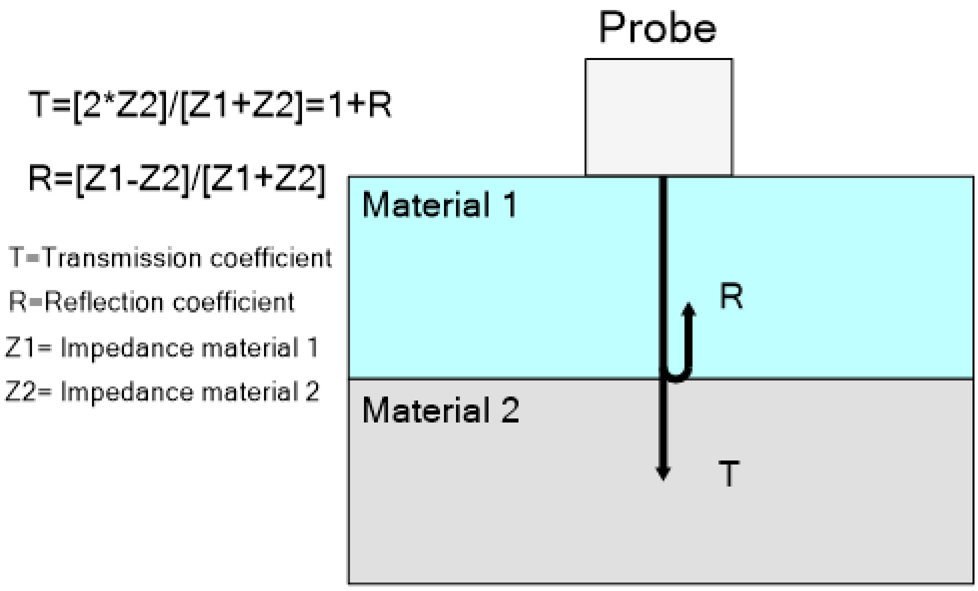

Figure 1 Reflection and Transmission coefficients (https://www.ndt.net/ndtaz/ndtaz.php)

The equations in Figure 1 illustrate that the reflection coefficient approaches zero as Z1 and Z2 approach the same values. In practice, this would mean that we can expect the interface signal between the coupling medium and the material under test to decrease as the impedance values approach the same value. If the reflection at the interface decreases, then the transmission increases and more sound pressure is available to move to the next boundary.

2. Method

A couple of experiments were set up to demonstrate the effect of impedance matching.

The first experiment used water and included a selection of tissue mimicking elastomers from Innovation Polymers to illustrate the water/polymer interface that might exist when using a wheel probe filled with water. See Figure 2 for schematic of setup.

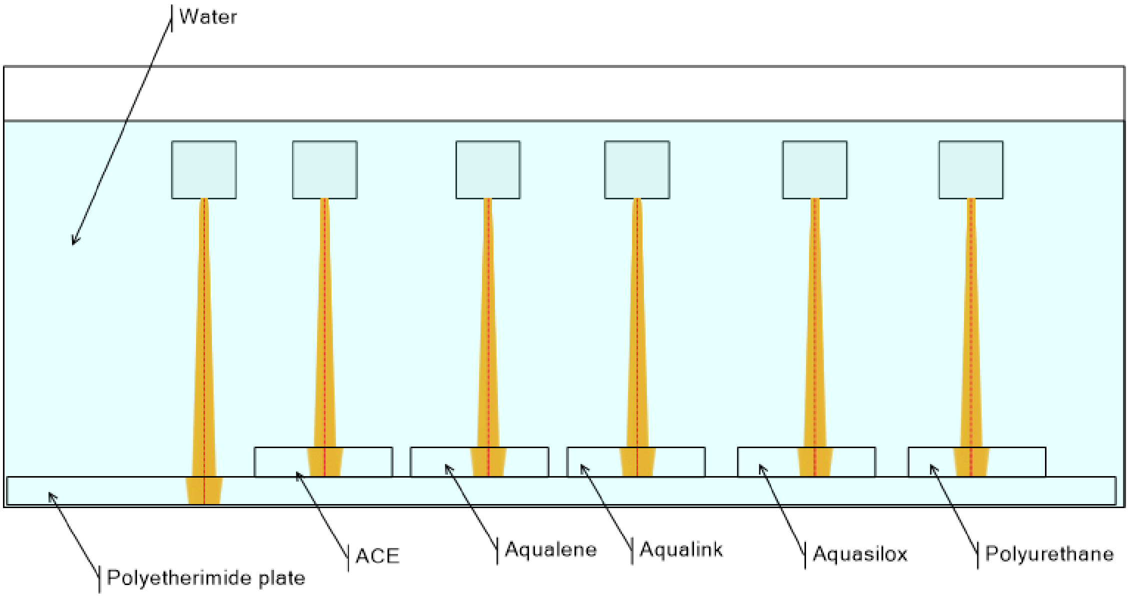

Figure 2 Impedance Matching to Water

The second experiment used a typical delay-line probe that would be associated with a thickness testing setup. For the delay-line option, a conformable material delay line in a novel holder was used. This design also allowed a demonstration of conformability to curved surfaces. See Figure 3 for schematic of setup. The holder is designed to support the elastomeric delay-line and also allow for it to deform as it is pressed against the test surface. Using a 3-legged holder allows the unit to be pressed to a solid stop-point that will always find a position that does not rock because the three legs will always terminate in the same plane.

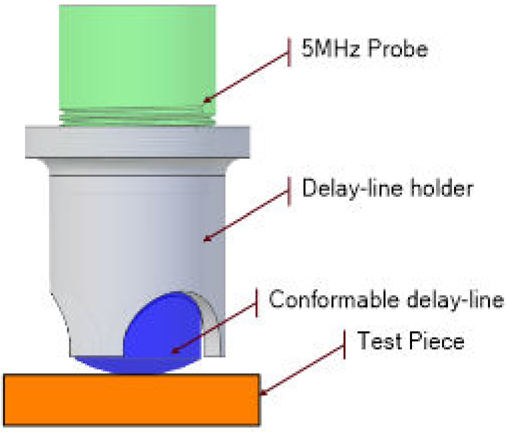

Figure 3 Impedance Matching to Elastomeric delay-line

The 3-legged holder and conformable delay-line will be seen to also provide an effective option for making contact on convex and concave surfaces.

3. Observations

Since the goal of this paper is to illustrate the effect of impedance on interface signals, A-scans are used to compare the interface and backwall signals.

For the immersion situation the test sample was a plate of polyetherimide (PEI) immersed in water. Table 2 summarises the acoustic impedances of the materials used.

Table 2 Acoustic Impedances of Polymers

Material	Acoustic Impedance (MRayl)	Delta Z water	Delta Z PEI
Water	1.48	0	-1.65
PEI	3.13	+1.65	0
ACE™ *	1.37	-0.11	-1.76
Aqualene™	1.49	+0.01	-1.64
Aqualink™	1.30	-0.18	-1.83
Aquasilox	1.11	-0.37	-2.02
Polyurethane	1.90	0.42	-1.23

*ACE, Aqualene and Aqualink are trademarks of Innovation Polymers

Comparing the acoustic impedance differences, we might expect that a wheel probe made of Aqualene™ would produce the lowest interface signal between the water in the tyre and the tyre itself.

The polymer samples were all in the range of 5mm to 6mm thickness. Any velocity difference between the water and small thickness of polymer will be seen as shift in arrival time of the polymer to PEI interface.

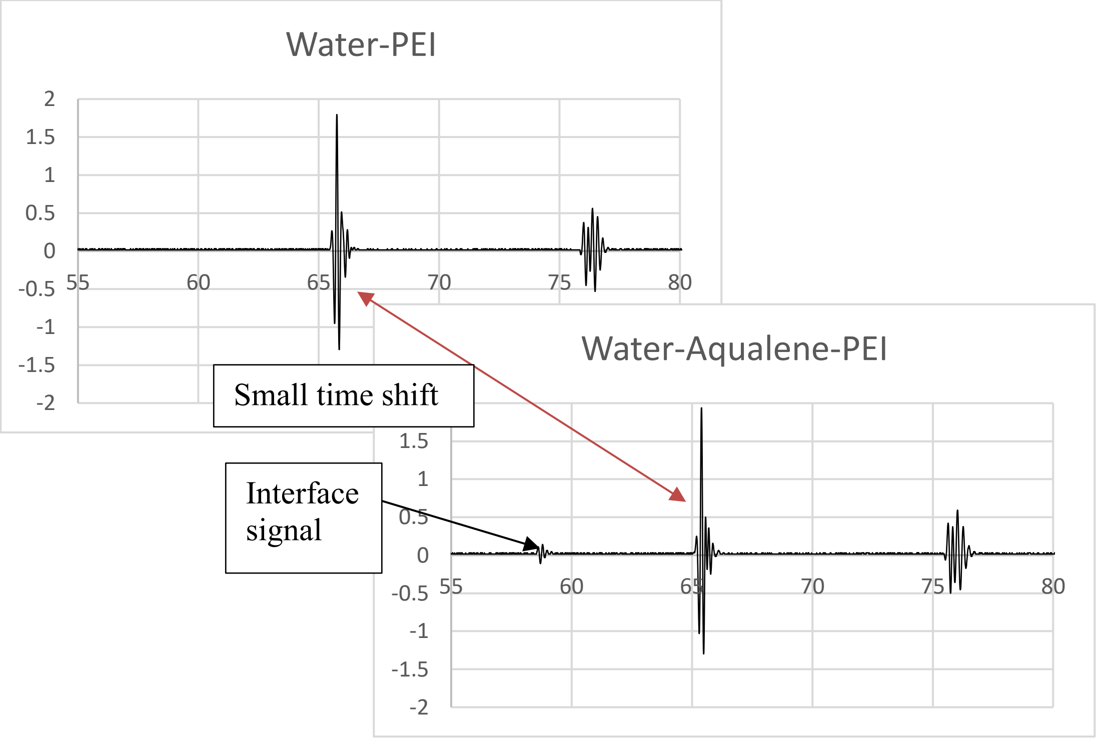

Figure 4 A-scan responses illustrating impedance matching to water

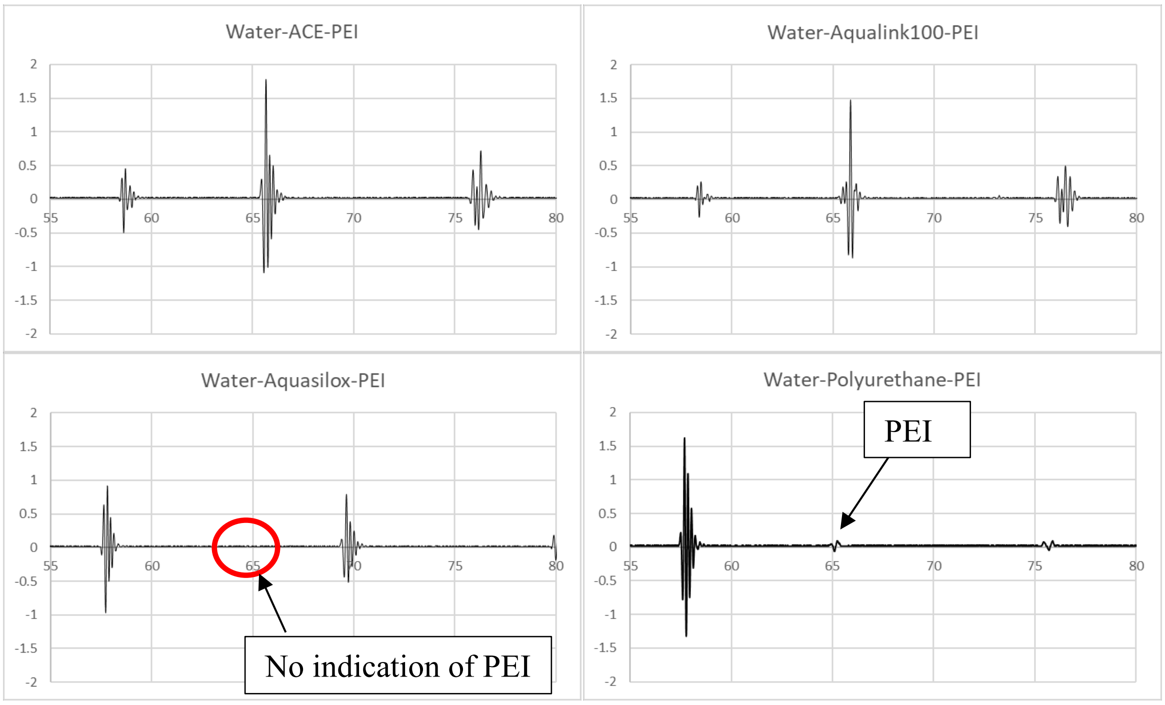

Figure 5 A-scan responses of impedance matching to water

Figure 5 shows A-scan responses for four other materials coupled to the PEI. In each case, the signal at approximately 57μs on the time-base is the water/polymer interface. ACE™ presents a slightly higher water/polymer interface signal than Aqualene™. Aqualink™ is between Aqualene™ and ACE™ with respect to the water/polymer interface signal. Of the remaining two polymers, Aquasilox shows a relatively lower interface signal than the polyurethane. However, the attenuation of the Aquasilox is higher than the polyurethane so the backwall signal from the PEI is not visible at all at the gain setting used and it is just barely visible with the polyurethane material between the water and PEI sample.

Selection of the polymer used as a delay-line can have similar considerations.

A delay-line made of Aqualink™ was used to obtain an A-scan from several materials. Because it is an elastomer, the pulse travel-time in the delay-line is not a constant. As the delay-line is pressed against the component being tested, the delay-line compresses. This changes the length from the probe to the point of contact. In an elastomer, this compression also changes the density and acoustic velocity in the elastomeric material[1]. However, since it is the time interval in the tested material that is of concern, the change in length of the delay-line is not a concern for the thickness test. Figure 6 shows the effect of compression on the conformable delay-line and the effect of acoustic impedance difference on two different test materials; steel and high-density polyethylene (HDPE).

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[1] Increasing the density and velocity of the elastomeric delay line, by compressing it in the holder, will slightly increase the specific acoustic impedance compared to that measured in the uncompressed state.

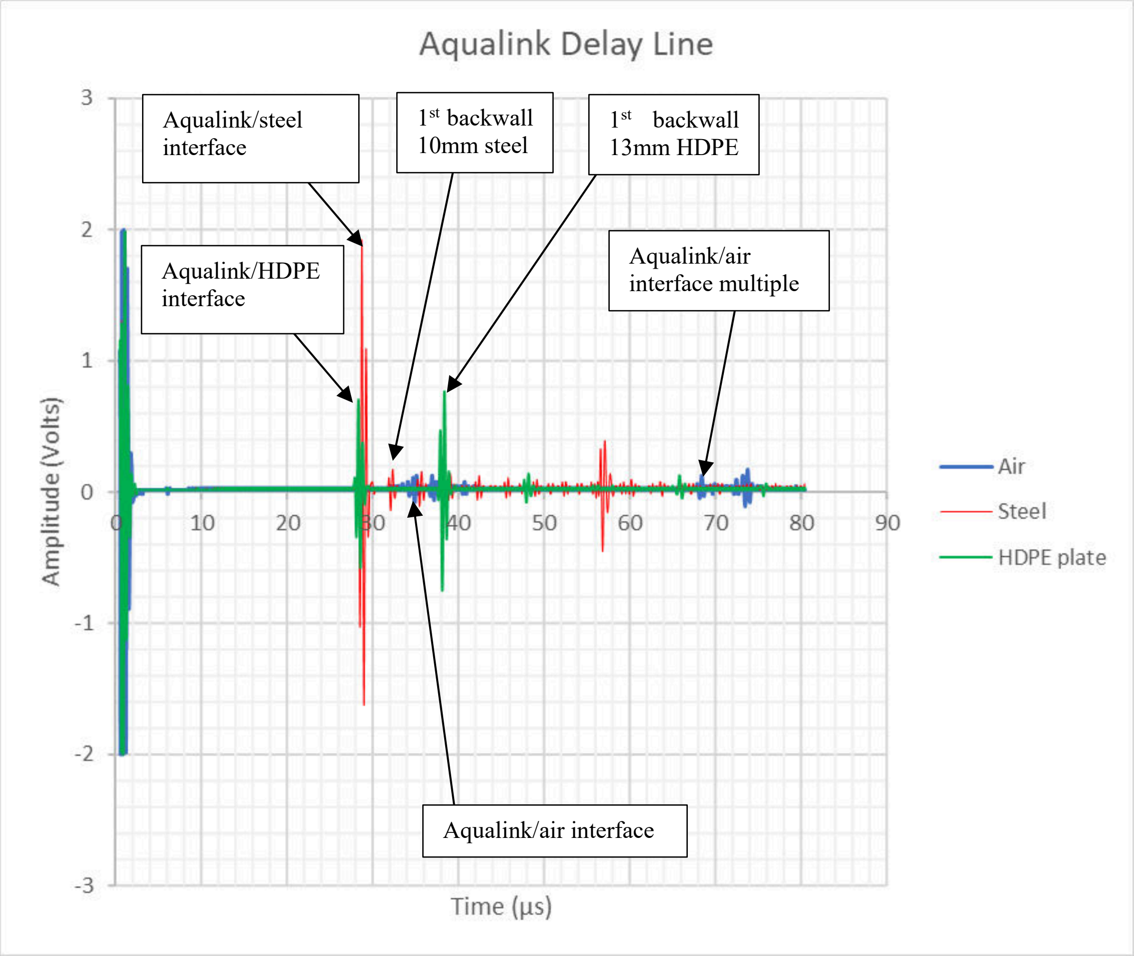

Figure 6 A-scan responses using a conformable delay-line

In Figure 6 the blue trace indicates the signal from the tip of the delay-line in air. This signal is quite small because the tip of the delay-line is convex to better accommodate geometries that might not be flat. The blue trace indications at approximately 34µs and 68µs indicate the time between the delay-line multiples. When pressed against the 10mm thick steel interface nearly eight multiples of the steel can be seen before the multiple of the compressed delay-line is seen at 57µs. The effect of impedance matching with the Aqualink™ delay-line can be seen by comparing the interface signal from the HDPE to the interface with the steel. The interface with the HDPE and steel have exactly the same starting point (28µs). However, the amplitude of the steel interface signal rises to nearly 2V whereas the HDPE rises to only 0.65V. Commensurate with the larger interface reflection, the steel multiples are seen to be very much lower amplitude with the third multiple of the 10mm steel step only reaching 0.15V. In spite of a much higher attenuation in HDPE, the first backwall achieves an amplitude of 0.8V and the second HDPE is multiple at 26mm is about 0.15V (about the same as the 30mm signal in steel).

Using the same gain settings as used to achieve the 10mm steel interface to nearly 2V amplitude, A-scans were captured for comparison on aluminium, PEI, polymethylmethacrylate (PMMA) and ultrahigh molecular weight polyethylene (UHMWPE). These are illustrated in Figure 7.

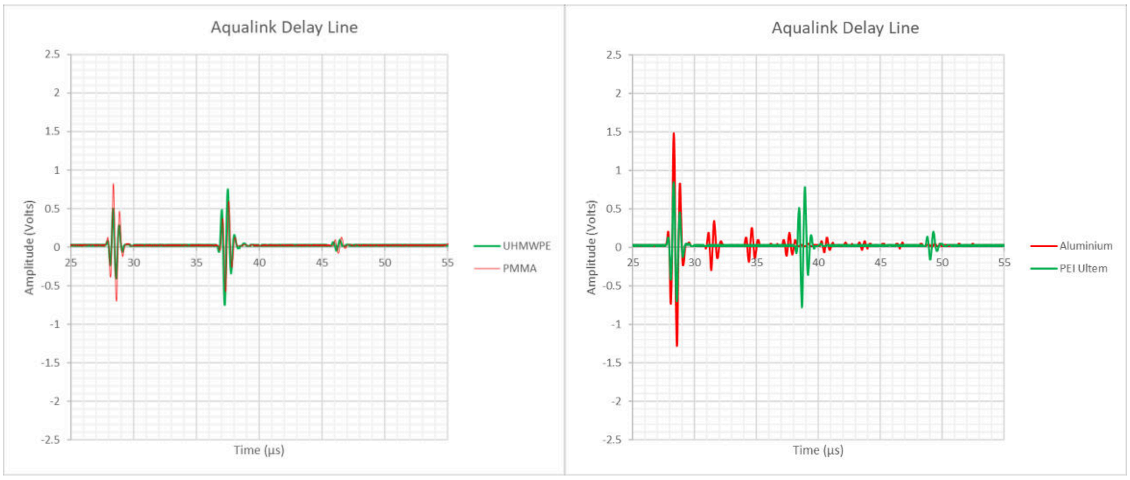

Figure 7 A-scan responses using a conformable delay-line to compare the effects of acoustic impedance differences

To indicate how the conformable wedge accommodates curved surfaces, the inside and outside surfaces of a HDPE pipe were tested. In addition, a small diameter steel pipe was tested from the outside surface. See Figure 8.

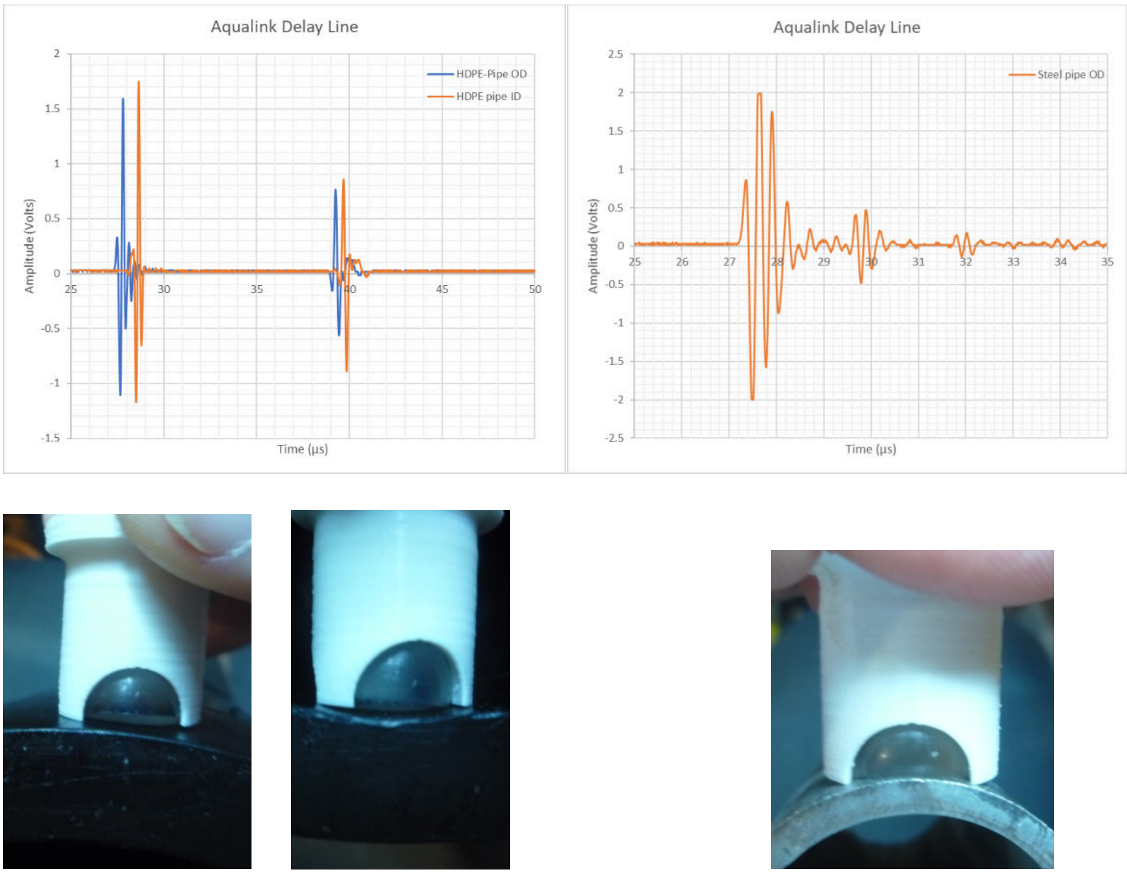

Figure 8 Conformable delay-line obtaining signals from inner and outer surface of HDPE pipe (IPS 6” DR 13.5) and stainless steel (NPS 1 ¼” Sch 40)

4. Conclusions

Selecting materials for ultrasonic equipment applications can be a set of compromises. Acoustic impedance should be a factor considered for wheel probes and for delay-lines used for thickness testing.

Although Aqualene™ is perhaps the best impedance match for wheel probes using water inside the tyre, its fracture toughness reduces its expected service lifetime. For more durable tyres, Aqualink™ and ACE™ may provide the durability that would be desirable. Then consideration would need to be given to the hardness of the material. With ACE™ being harder (Shore A 34), it is better able to resist flexing. In spite of its high attenuation, polyurethane is a popular material for rail-testing wheel probes where the service temperatures may range from -50°C to 90°C. For applications in excess of 100°C tyres made of Aquasilox have proven effective but require extra down-pressure to maintain adequate contact for ultrasonic coupling.

Delay-line probes made of conformable elastomers have been demonstrated to improve acoustic impedance matching on several polymers. Cross-linked polystyrene has been traditionally used as an effective low-velocity delay-line because of its relatively low attenuation. Low velocity elastomers such as ACE™, Aqualink™ and Aqualene™ have slightly higher attenuation than polystyrene; however, because they all have lower velocities than polystyrene, they can obtain similar results because the delay-lines can be shorter to obtain a similar working time interval in metals and the conformability of the elastomeric delay-lines allows curved surfaces to be tested without the need to machine the delay-line to fit a specific curvature.