NDT OF BUTT FUSION WELDED PEHD PIPES

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ABSTRACT

The application of construction plastics will continue to rise with the development and increased use of non-destructive testing to detect faults and reliably characterize the flows. Non-destructive testing is cost-effective and hence has beneficial economical effects on quality assurance.

1. PROBLEMS GENERALS

The popularity of PEHD piping can be attributed to its lightness, flexibility and good corrosion resistance, as well as the ease with which is can be joined. For areas where the application is critical, or the pipes are of large diameter and of thicker section, the butt fusion process is performed. Both of these heat fusion processes are capable of producing a joint with mechanical properties approximately equivalent to those of the parent material [1, 3, 7].

The application of construction plastics will continue to rise with the development and increased use of non-destructive testing to detect faults and reliably characterize the flows. Non-destructive testing is costs-effective and hence has beneficial economical effects on quality assurance [4].

2. NDT OF PEHD PIPES

2.1. VISUAL INSPECTION

The most widely used technique is a visual inspection of the outer weld bead. This method is only sensitive to gross flaws such as pipe misalignment or defects inferred from the presence of an abnormal weld bead. The limitations of a visual technique, such as this, must be realised; a poorly formed bead may reliably indicate an unsatisfactory weld, but a correctly formed bead is not always a sure indication that the weld is satisfactory and free from internal defects.

2.2. ULTRASONIC NDT

Figure 2.1. show that the attenuation of ultrasound in polyethylene is directly proportional to the frequency of vibration of the ultrasound, and also shows that PEHD attenuates ultrasonic shear waves much more rapidly that compression wave [6].

Essentially, this means that for many practical applications, ultrasonic testing is limited to using low-frequency compression waves (*ie* < 4MHz) in order to achieve sufficient penetration and sensitivity on typical thicknesses (25 mm) and grades of PEHD.

This technique has been evaluated on a range of PEHD pipe specimens containing precise simulated defects.

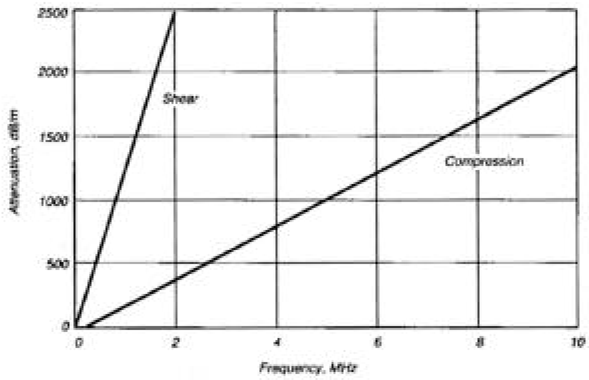

Figure 2.1. Attenuation of ultrasound of various frequencies propagating through PEHD at room temperature

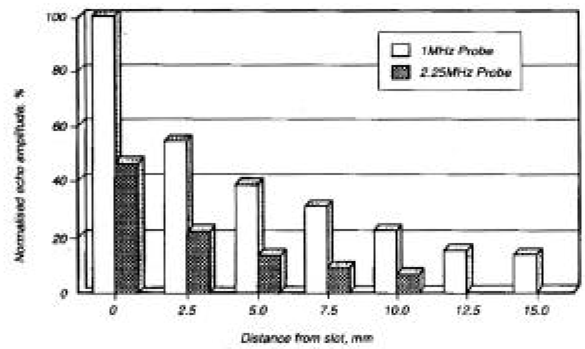

Figure 2.2. Pulse-echo creeping wave response from 3 mm deep saw cut in PEHD [6]

Pulse-echo experiments on a 10 mm-thick PEHD test block containing very fine (<250 µm) saw-cuts were used to determine the sensitivity of the creeping wave technique, and to assess its suitability as a method for inspecting the region immediately beneath the outer weld bead on PEHD pipe. Apparent that the generation of creeping waves in the PEHD block was heavily dependent on the quality of coupling at the specimen interface. For this reason it was necessary to use a large amount of water-based couplant during scanning [5].

Three creeping wave probes with centre frequencies of 1, 2.25 and 3.5 MHz were evaluated. Each probe was positioned 5 mm away from the free edge of the test block and the magnitude of reflected creeping wave signals were compared. The 1 MHz probe gave a response that was well over 20 dB higher than an otherwise identical 3.5 MHz probe. At a range of 5 mm, both the 1 MHz and 2.25 MHz frequency probes could detect a saw-cut extending to a depth 3 mm from the block surface. However, the magnitude of the reflected creeping wave signal decays rapidly as the distance between the probe and saw-cut is increased (figure 2.2).

The creeping wave probe was positioned against the outer weld bead and then scanned around the circumference of each pipe. During scanning, a strong reflection from the outer weld bead is detected and is clearly identifiable on the A-scan display. This signal can be used to ensure that transmission of ultrasonic energy from the ultrasonic transducer into the PEHD pipe is maintained during scanning [6, 8].

In the inspection, the creeping wave A-scan response from the 6 mm-diameter foil insert is shown in figure 2.3. During fabrication of this specimen, each foil disc was positioned in the mid-thickness of the pipe wall, and an inspection using creeping waves, which are only sensitive to imperfections close to the surface where they are generated, would have not been expected to detect very much. Clearly, in this case, the final position of the 6 mm disc is such that interaction with the creeping wave does occur. The creeping wave technique was able to detect the presence of both the 6 and 10 mm-diameter discs, but not the other discs. A creeping wave inspection of the two other defective specimens (cold weld), did not detect any significant variation in response from the fusion area immediately beneath the outer weld bead [1, 2].

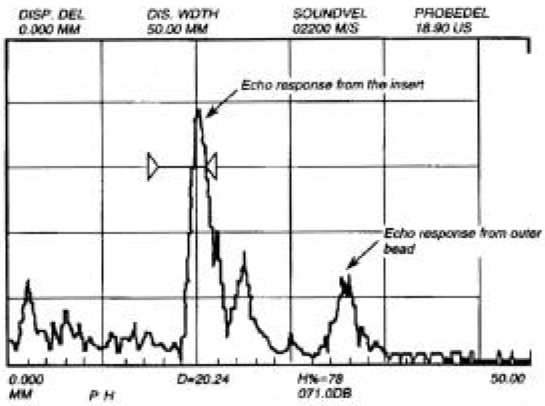

Figure 2.3. Pulse-echo creeping wave A-scan response from 6 mm diameter foil insert [6]

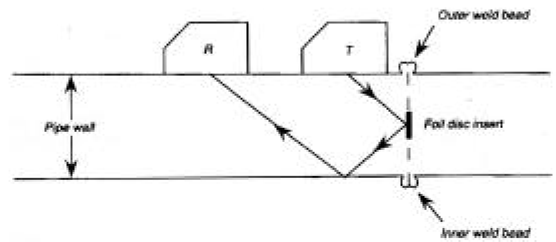

Figure 2.4. Probe configuration for tandem inspection [6]

The probe configuration for the tandem inspection technique [6] is shown in figure 2.4. Tandem inspection is particularly sensitive to flaws orientated perpendicular to the scanning surface and, for this reason, is potentially suited to detecting lack-of-fusion type defects in butt welded PEHD pipe work. However, it is only practical to generate angled compression waves in the PEHD, as shear waves are attenuated too rapidly. In addition, for typical pipe wall thicknesses of around 25 mm, the separation distance between the transmitting and receiving transducers is significantly reduced, and the use of 45° probes becomes impractical. This is the case when considering the tandem technique to inspect the 25 mm-thick PEHD pipe specimens. To overcome this problem, all tandem experiments were performed using PTFE wedges *(ie* wedge angle is 30°), and compression wave transducers in order to generate 60° angled compression waves in the PEHD. The base of each wedge was modified to fit the curvature of the pipe [7, 8].

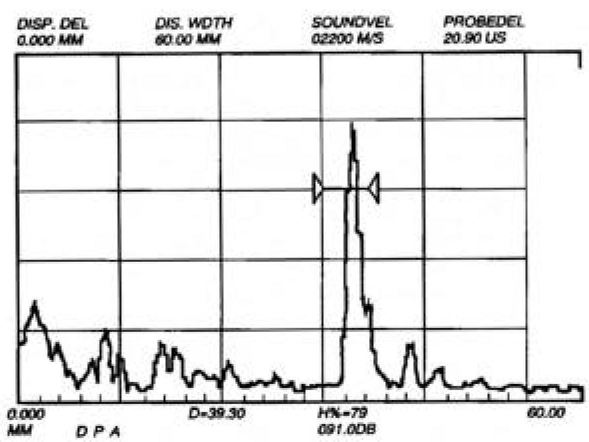

Figure 2.5. A-scan response from perpendicular reflector located in mid-thickness of pipewall, inspected using the tandem technique [6]

The experiments showed that, for the tandem inspection of 25 mm-thick PEHD, 1 MHz probes gave an improved signal-to-noise performance over 2.25 MHz probes. A probe frequency of 1 MHz was selected for all subsequent tandem scans. Figure 2.5 shows a typical A-scan response from a perpendicular reflector detected using the tandem technique [6].

2.3. X-RAY RADIOGRAPHY

The exposure charts [6, 8], for each of the PEHD, use radiographic intensities between 10 kV and 16 kV inclusive. At such low intensities a number of questions or difficulties can arise: (a) the X-ray equipment has a maximum output of 160 kV and is not specifically designed for low-kV X-rays, but it is being used at the lower extreme of its operating range to output intensities as low as 10 kV; (b) for low kVs the exposure time may be unnecessarily large; (c) the equipment may indicate a low-kV reading on the dial which may be different from the actual output, and which may also vary from set to set; (d) the output may vary each time the set is switched on; (e) the absorption by the air between the source and specimen may be comparable to the absorption by the test specimens [6, 7, 8].

TWI has pioneered the use of wire-type Image Quality Indicators (IQIs) made from PEHD to the specifications of BS EN 462-1. The existence of such IQIs is a major achievement and significantly helps to overcome the problems of describing image quality of radiographs shot at low X-ray energies. It was concluded that the very low absorption by PEHD of X-ray radiation can vary significantly from one PEHD type to another but that, for the range of PEHD materials shown in table 2.1, only two exposure charts are necessary to produce radiographs in the density range specified by BS 2600 [6].

Table 2.1. Product specification of medium to PEHD [6]

**Product	Colour	Density (g/cm^2)	Yield strength (N/mm^2)	Modulus (N/mm^2)	Application
1. Dowlux	White	0.937	17	710	Heating, installation, irrigation pipes
2. Finathene 3802 B	Black	0.948	19	700	Anticorrosive coatings, cable jackets
3. EltexTUB 121	Black	0,958	25	1200	Gas pipes, industrial fluid transportation
4. EltexTUB 124	Dark blue	0.951	25	1200	Water transportation(drinking)
5. *Finathene 3802	Light blue				Water transportation(drinking)
6. Finathene 3802 Y	Yellow	0.941	19	700	Gas distribution systems
7. Eltex TU B 125	Orange	0.951	25	1200	Gas transportation

* Details not supplied by manufacturer
** These are the Trade Names of the products as supplied by Stewarts and Lloyds Plastics [6]

A wide range of experiments were repeated using different thicknesses of PEHD and a different intensities. These experiments were also used as a check on the earlier exposure charts. It was found, for example, tha using X-ray energies of between 16 kV and 26 kV, the exposure times were kept to the order of 1 minute. Below 16 kV, the exposure times required to achieve the radiograph densities in the range specified by BS 2600, were unnecessarily large. Above 26 kV the exposure times were too short to achieve reproducible density readings on the radiographs. So, it is clear from these experiments that low kVs are necessary, but perhaps not as low as 10 kV [6].

To check the repeatability of the output intensity of X-ray tubes designed for relatively high X-ray energies, but working at low X-ray energies, radiograph density measurements were taken every 24 hours over a five-day period on a 20 mm-thick PEHD block, with all the other parameters remaining the same.

The range of experiments conducted to assess whether low kV was necessary were also used to check previous exposure charts and to produce updated ones with tighter tolerances on required radiographic densities. The new charts replace those in [6], and now a finer focal spot size is used, in line with a shorter focus-to-film distance. The two new exposure charts (figure 2.6 and figure 2.7) cater for the following groups respectively [6]:

Group (a)		**Group (b)**	
Dowlex 2343 E	white	Finathene 3802	light blue
Finathene 3802 B	black	Finathene 3802 Y	yellow
Eltex TV B 121	black	Eltex TU B 125	orange
Eltex TU B 124	dark blue		

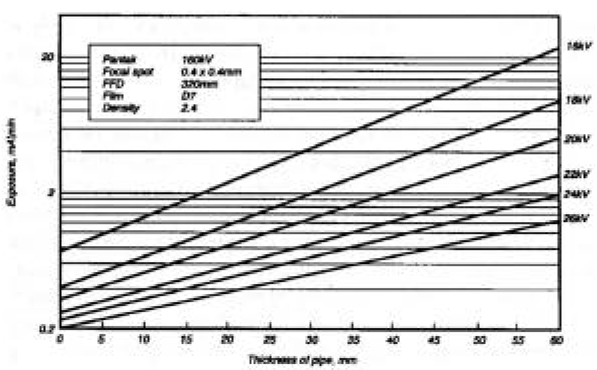

Figure 2.6. Exposure charts for group (a) PEHD materials; Dowlex 2343E, Finathene 3802 B, Eltex TU B 121, Eltex TU B 124 [6]

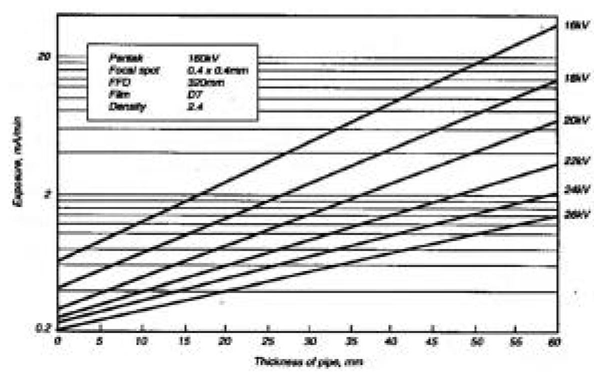

Figure 2.7. Exposure charts for group (b) PEHD materials; Finathene 3802, Finathene 3802 Y, Eltex TU B 125 [6]

For a different PEHD to those in group (a) and (b), it will be necessary to produce a separate exposure chart (BS 2600). To do this, step wedges covering the thickness range of interest will need to be manufactured. It has not been confirmed why the PEHD considered fall into these two groups, with regard to their absorption of X-rays. This variation in X-ray absorption is in contrast to the way the materials respond to ultrasonic energy. Whilst there are variations in ultrasonic wave velocities and attenuation, these are not sufficiently large to require separate calibration blocks for setting sensitivity. There does not appear to be any correlation between the division of the PEHD for radiography and their product specifications given in table 2.1.

It is worth noting that the above exposure charts were produced from step wedges manufactured from flat plaques, using the same PEHD pellets as for the pipes. In order to use the above exposure charts for inspecting pipes, it is important to confirm that the plaques do not have significantly different X-ray absorption properties than the pipes. For a given PEHD and thickness, the plaques were 1-2% more absorbent of X-rays than the pipes, that is, the radiographic densities for plaques are 1-2% lower than radiographic densities for the corresponding pipe material.

Table 2.2. A comparison of the radiographic densities in PEHD pipe with and without the presence of a 5 mm thick Finathene 3802 Y, using air as a medium [6]

Milli Amps	Time, seconds	Intensity, kV	Radiographic density	
			With 5 mm 3802 Y plaque	Without 5 mm 3802 Y plaque
1	60	14	1.17	2.17
1	39	16	1.11	2.19
1	30	18	1.38	2.57
1	20	20	1.23	2.17
1	15	22	1.16	1.95
1	13	24	1.23	2.02

Previous work on Image Quality Indicators (IQIs) considered a comparison between various IQI types manufactured from PEHD; ASME plaques with holes (ASME V Article 22), step wedges with holes, and wire types. Of these, the wire types proved to be the most appropriate from the point of view of IQI sensitivity and avoiding the need of numerous spacers normally associated with step/hole type IQIs [6, 7, 8].

For testing PEHD pipes, a table of IQI sensitivity has been produced (table 2.3), covering the PEHD thicknesses of interest here, and indicating the minimum number of wires that should be visible on the radiograph [6]. The IQIs used to produce table 2.3. Table 2.3 considers normal and critical techniques and represents what is possible under laboratory conditions.

Table 2.3. IQI sensitivity for critical and normal techniques [6]

Specimen thickness, mm	Section A Critical techniques	Section B Normal techniques
	Minimum no. of wires visible	Minimum no. of wires visible
5	7	6
10	5	4
15	5	4
20	5	4
25	5	4
30	5	4
35	5	4
40	4	3
45	4	3
50	4	3

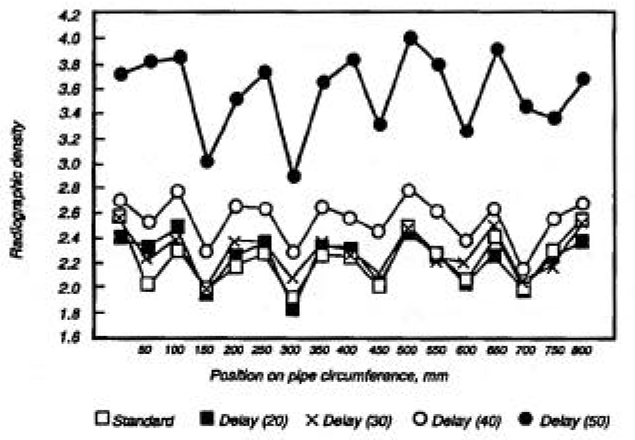

Figure 2.8. A comparison of radiograph density versus position around the pipe circumference, for: a) a standard weld; b) a weld with 20 s plate removal time; c) a weld with 30 s plate removal time; d) a weld with 40 s plate removal time; e) a weld with 50 s plate removal time [6]

In the light of the new exposure charts it was decided to radiograph the four pipe specimens. In this way the radiographic density of a standard pipe *(ie* welded under optimum conditions), measured at a number of positions around the pipe's circumference, could be compared with the radiographic densities at identical positions on the pipe specimens welded with various plate removal times. The results are illustrated in figure 2.8, where a standard pipe is compared with a number of PEHD pipe welds manufactured with delay times of 20 s, 30 s, 40 s and 50 s. The increase in radiograph density, corresponding to an increase in plate removal times, is clear for the 40 s and 50 s delay cases [6, 7, 8].

2.4. THE US AND Rx IN BUTT WELDED PEHD PIPE SYSTEM

The ultrasonic and radiographic techniques considered demonstrate an ability to detect a range of flaw types in butt welded PEHD pipe systems. However, despite an ability to detect flaws, the relationship between flaw size and pipe lifetime remains undetermined and, at this stage, it is not known whether the flaws detectable by these NDT techniques are of a critical size or not. In order to realise the full potential of PEHD pipe, it is important that a critical flaw size is determined and that acceptance criteria, to which butt welds in PEHD can be inspected, are specified. The effect of contamination of the fusion face of butt welds in PEHD has been investigated [1÷9], but this and other work has yet to establish a maximum allowable flaw size for PEHD pipe operating in a range of common working conditions.

The detection capabilities of the two NDT methods evaluated are displayed in table 2.3 for detecting defects in butt welded PEHD pipes. Ultrasonic tandem and TOFD techniques have shown that they are able to detect reliably a lack of fusion down to 2 mm in through-thickness height. Low-kV radiography has demonstrated a similar level of sensitivity to these flaws but, in addition, is sensitive to gross particle contamination of the fusion face (chalk dust).

Ultrasonic tandem and TOFD images of pipe display a variation in signal between areas known to contain chalk dust and areas that are dust-free. However, further work is needed to establish whether this variation in signal is truly due to the chalk dust or whether it is due to another feature of the weld, such as a variation in bead condition, for example.

The ultrasonic techniques considered did not appear to be sensitive to nominally cold welds. However, the practical application of an ultrasonic technique is arguably more straightforward than radiography, and should not be overlooked as a means of inspection [6].

Table 2.3. The capabilities of ultrasonic and radiographic NDT techniques for detecting defects in butt welded PEHD pipes

√ - Detectable

(√) - Technique currently being developed and showing some progress

× - Not detectable

* There may be lower limits to the amount of dust contamination detectable using radiography

▲ Near surface flaws only

		Lack of Fusion	Dust Contamination	Cold Weld
	RADIOGRAPHY	√	√*	√
ULTRASONICS	Angled compression waves	√	×	×
	Creeping wave▲	√	×	×
	Tandem	√	(√)	×
	Time of flight diffraction	√	(√)	×

3. CONCLUSIONS

3.1. Nondestructive testing is cost-effective and hence has beneficial economical effects on quality assurance.

3.2. Visual inspection is only sensitive to gross flows such as pipe misalignement or defects inferred from the presence of an abnormal weld bead.

3.3. Ultrasonic techniques are currently unable to detect nominally cold weld.

3.4. Radiographic intensities of between 16 kV and 26 kV are optimum when inspecting thickness of polyethylene pipe between 5 mm and 50 mm.

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