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Non-Destructive Ultrasonic Inspection to Detect Flaws in Plastic Pipe Walls and Joints – Correlation with Lab Testing

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ABSTRACT

Ultrasonic detection equipment was used to investigate defective pipes and fusion joints. The following examples of its application are presented.
Electro-fused joints were tested in four different 110mm PE100 and PEX pipes. The PEX pipes showed a less complete fusion between pipe and fitting in comparison to PE100 pipe, although there are also differences between the three types of PEX pipes. The slightly poorer joints showed internal surfaces at the fusion plane and hence a lower homogeneity of the fused material. These differences in joint quality correlate with the results of a new long-term testing method (the Slow Peel test) on the same four electro-fused joints. The differences noted by ultrasonic and Slow Peel testing were not seen using the traditional Peel test according to ISO 13954 at 23°C, performed in a tensile testing machine.
PE pipes with many voids resulting from poor extrusion procedures were also inspected. At each of three locations in the pipe wall, more than one hundred individual voids could be counted. Butt-fused joints in these pipes also contained many voids. This correlated well with very poor tensile test results obtained on these joints.
A defective jacket pipe from a district heating (hot water distribution) pipeline was investigated. Constant Tensile Load tests at 80°C according to EN 253 on strips taken from the jacket pipe showed a sub-standard long-term quality. Again, several voids were detected in the wall of the jacket pipe and these had clearly served as crack initiation sites.
A further example was also from a district heating system. Jointed Polyethylene plugs to fill up holes in a shrink-sleeve were investigated.
A brief comparison with other imaging techniques for defective PE pipe materials was made.

INTRODUCTION

Non-destructive inspection of plastics pipes and joints is very attractive. By using ultrasonic inspection equipment for example, important information on defects and holes in a pipe wall or a joint can be obtained [1]. Detecting such flaws allows timely corrections in production techniques and procedures and will prevent some premature failures from occurring.
This publication provides examples of how ultrasonic inspection and imaging equipment was used to support laboratory tests and investigate field failures.

MATERIALS AND METHODS

Materials

All investigated materials consisted of polyethylene (PE) and cross linked polyethylene (PEX) pipe materials, which were commercially available.

The first investigation was performed on electro-fused joints in three types of 110mm SDR11 cross linked polyethylene pipes. The pipes investigated were electro-fused peroxide cross linked PEXa, silane cross linked PEXb and electron beam cross linked PEXc. For comparison, an electro-fused 110mm SDR11 PE100 pipe was also investigated, which was denoted “B”. The three PEX pipes were denoted A, C and D, but not necessary in the order given above.
The joints were made using commercially available couplers produced from PE100 resin, using the normal jointing procedures prescribed by the coupler manufacturers, after producing well-scraped external pipe surfaces.
The second investigation was performed on a HDPE pipe that contained many small internal voids originating from poor extrusion conditions. The pipe was used as a jacket pipe for communication cables. Butt-fused joints in these pipes made during pipe installation also contained voids that were visible with the naked eye, after cutting.
The third investigation was performed on a jacket pipe of a district heating system.
The fourth investigation was performed on poorly jointed and therefore leaking plugs in a jacket pipe from a district heating system.

Methods
All electro-fused joints were tested with the standard Peel test at 23 °C according to ISO 13954:1997 or with a long-term test at 95 °C, the Slow Peel test [2], lasting up to 500 hours.

The equipment used for the ultrasonic investigations was an AIM33 imaging and inspection system produced by Inde Systems, South Korea. The inspection work was performed at KNDT&i Co, Ltd. in South Korea. The probe frequency was 7.5 MHz in all cases.

Other tests were tensile testing at 23 °C and Constant Load testing at 80 °C at 4 MPa in 2% Arkopal detergent, on a district heating jacket pipe according to EN 253.

RESULTS

1. Electro-fused PE and PEX pipes

Ultrasonic imaging
Figure 1 to Figure 4 show images made of joints in pipes A to D with the ultrasonic equipment. Several images of each joint were made, with slightly variable joint qualities within each joint, but only 1 image per joint is shown.
The joint in pipe B (PE100 pipe) is best. The joints in the other 3 pipes, all PEX pipes, show many locations with incomplete fusion. The back wall echo of the incompletely fused joint interfaces is worst for the joints in pipes A and D.
The observations indicate that joints A and D have a lower quality than joints B and C.

Peel tests
Peel tests at 23 °C according to ISO 13954 on all 4 types of electro-fused joints (A, B, C and D) showed satisfactory results.
Figure 5 shows the results of Slow Peel tests performed on the same joints, on 4 test bars of each joint type. Figure 6 to Figure 9 show some of the test bars after 500 hours of testing in the Slow Peel test. The results are quite different. Joints A and D show relatively short times-to-failure. The joint in pipe C is much better and shows only partial peel-off, while joint B is best. It only shows failure in the pipe and not in the joint area.

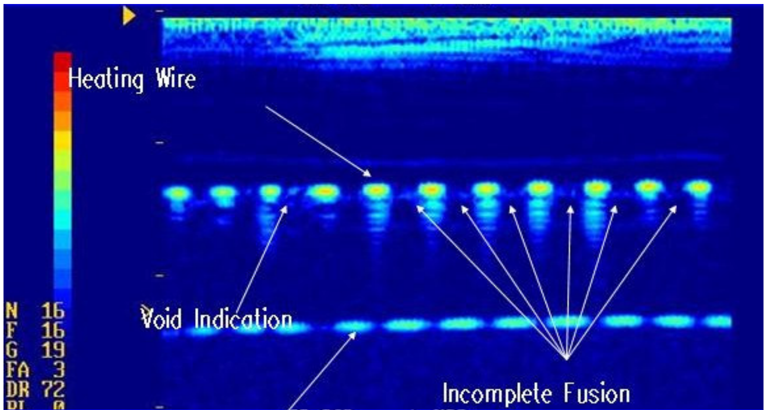


Figure 1. Ultrasonic inspection image of electro-fused joint in pipe A. Arrow in lower left corner indicates back wall echo. There are many signs of incomplete fusion.

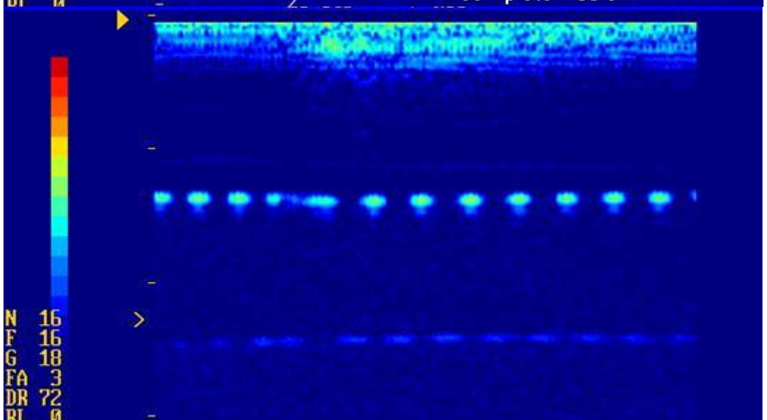


Figure 2. Joint in pipe B, showing acceptable joint quality.

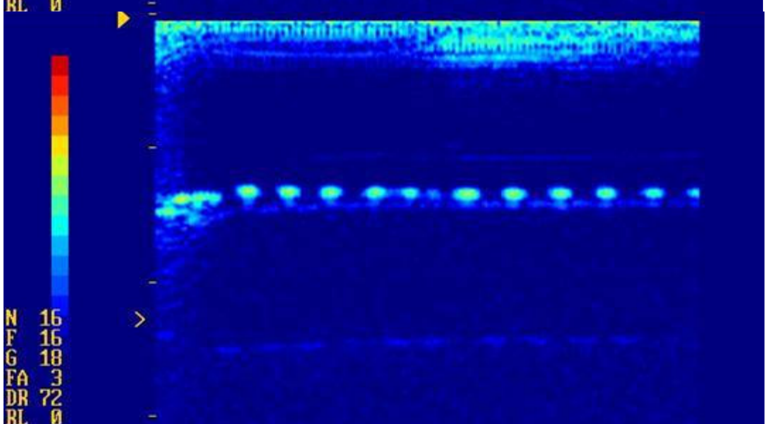


Figure 3. Joint in pipe C with some locations of incomplete fusion. Other locations in this joint show more incomplete fusion than this. On the left is an indication of a cold zone.

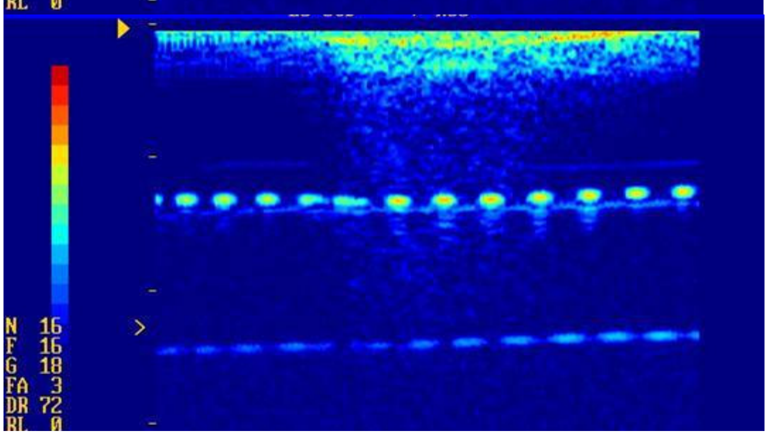


Figure 4. Joint in pipe D.

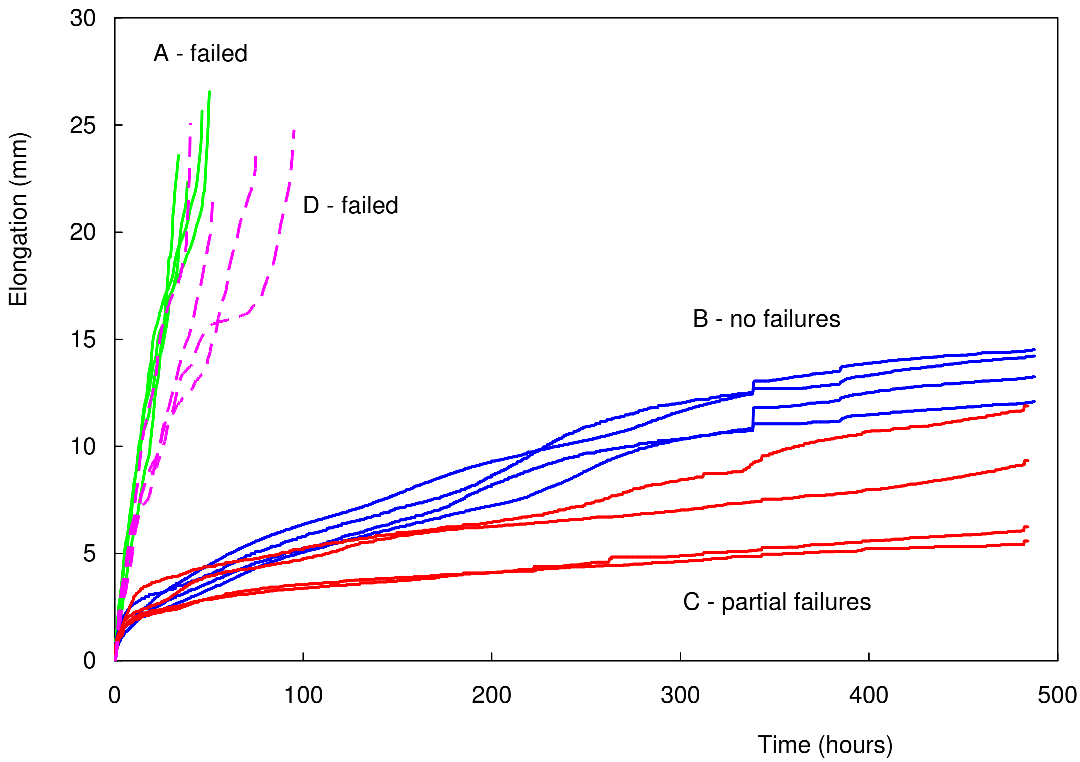


Figure 5. Elongation of 4 test bars taken from each of the 4 types of electro-fused joints during Slow Peel testing at 95 °C.

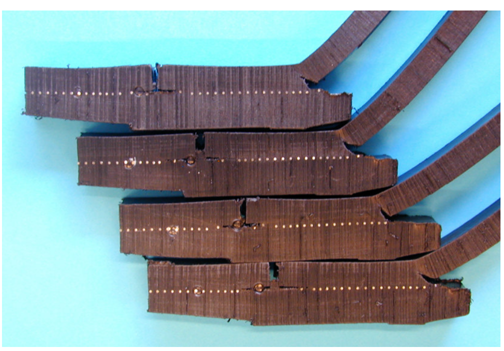


Figure 6. Test bars from a joint in a PE100 pipe "B" after Slow Peel testing.

Figure 7. Enlargement of Figure 6.

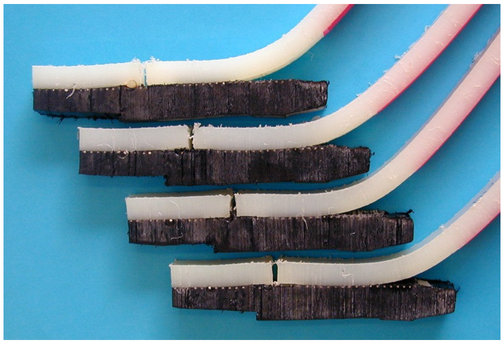


Figure 8. Test bars from a joint in PEX pipe "C" with partial joint failure after Slow Peel testing.

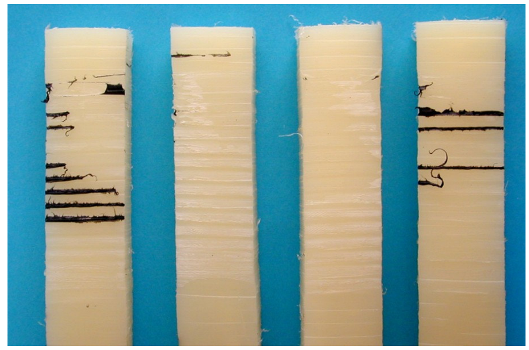


Figure 9. Test bars from an electro-fused joint in PEX pipe "D" after complete peel-off in the Slow Peel test.

Table 1. Results of Slow Peel Tests on the same 4 types of joints as in Figure 1 to 4.

Pipe	Time to failure (hours)				Result
Test bar	1	2	3	4	
A	34	39	46	50	Peeled off completely
B	> 487	> 487	> 487	> 487	No joint failure; brittle pipe failures
C	> 484	> 484	> 484	> 484	Partial peeling off
D	75	40	95	52	Peeled off completely

2. PE80 communication cable jacket pipe with voids

Test bars taken from the wall of an ill-produced communication cable jacket pipe that had failed during trench-less installation were investigated. Figure 10 shows the voids in the pipe wall. All six test bars taken from non-fused pipe showed an Elongation at Break below 295 % (lowest value 82%). Six test bars from a butt-fused joint in this pipe had a very low average Elongation at Break of only 12%.

Figure 11 shows an example of the ultrasonic image of such a test bar. At three different locations, a total number of 141, 145 and 108 individual voids could be counted respectively.

Figure 10. Test bars from a PE pipe with internal voids and a butt fused joint.

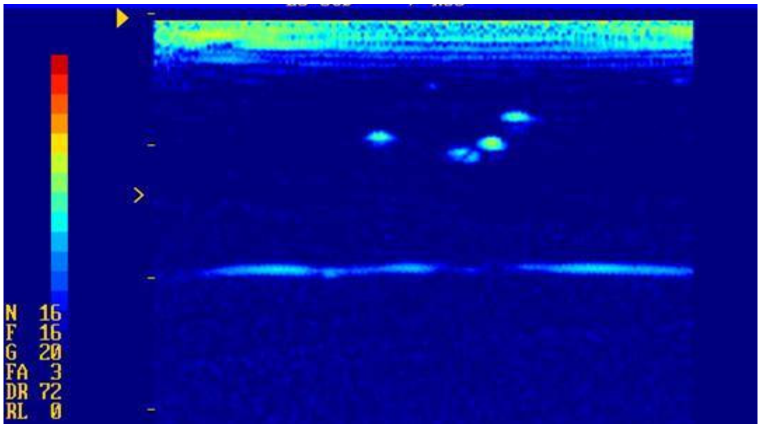


Figure 11. Ultrasonic image of the pipe in Figure 10 showing internal voids.

3. PE jacket pipe of a district heating system

Several years ago, a district heating pipe had become defective after about 8 years of service. It appeared that the jacket pipe had failed. Constant Load tests on the jacket pipe proved that the geometric mean of the time-to-failure in the Constant Load test according to EN 253 was only 145 hours, while 1500 hours was required.

It appeared that the jacket pipe had been produced from thin pre-heated foils that had been wound on top of each other, until the required wall thickness was reached. Due to incomplete fusion between the consecutive foil layers during production, holes had formed between the foils (Figure 12).

Figure 13 shows that ultrasonic imaging makes the voids between the adjacent foil layers clearly visible. Non-destructive ultrasonic inspection after production could have prevented delivery of such a jacket pipe.

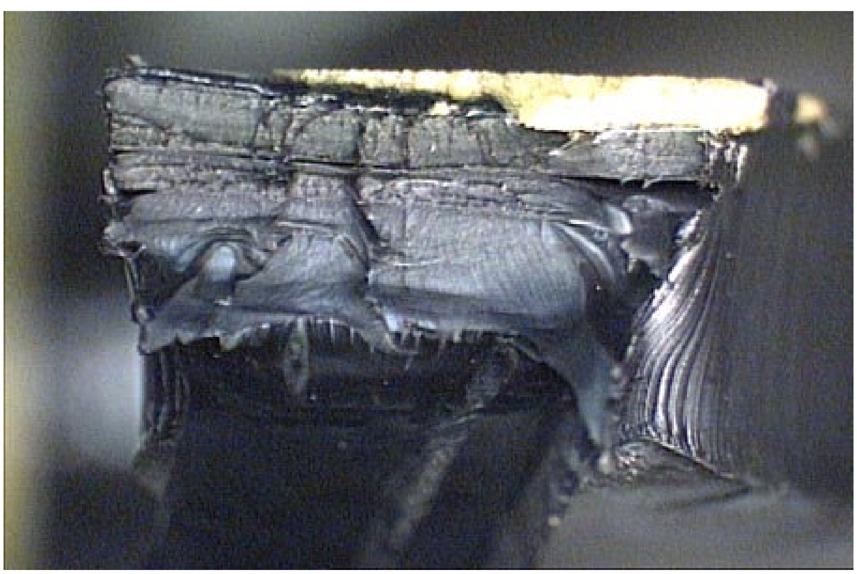


Figure 12. Wall of a PE jacket pipe from a district heating system after failure, showing the different layers of foils and the voids in between.
Top layer: yellow Polyurethane heat-insulation foam.

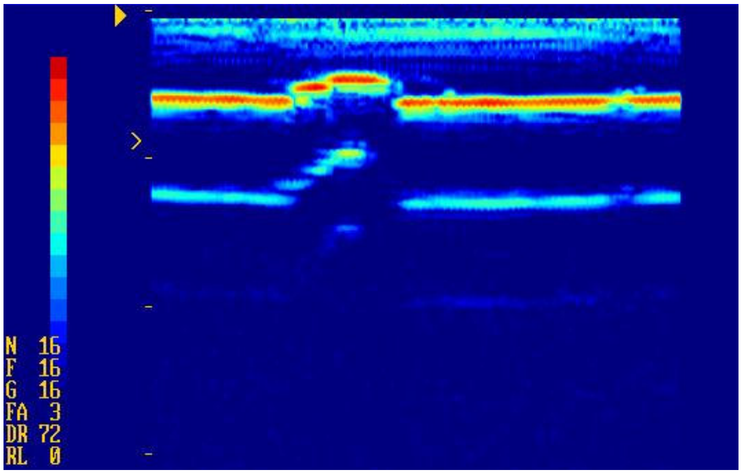


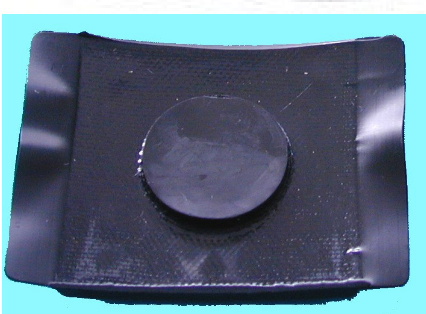
Figure 13. Ultrasonic image through the wall of the PE jacket pipe in the previous Figure. Holes in axial direction between the adjacent foil layers in the pipe wall are clearly detected.

4. Poorly fused plugs in a district heating system

Connections can be weak links in district heating systems. If errors during jointing are made, leak paths for groundwater may be formed. Water ingress into the Polyurethane foam insulation layer below the jacket pipe may occur, followed by degradation and shrinkage of the foam layer, which then loses its heat insulation properties. More ingress of water occurs, which then heats up because of the lost heat insulation properties of the foam. This eventually leads to corrosion of the steel medium pipe. Finally, this chain of events makes very expensive repairs necessary. Leak prevention is crucial.

Connections in the Polyethylene jacket pipe are often made with shrink sleeves, which are heat-shrunk onto the external surface of the jacket pipe. The space below the sleeve needs to be filled up with additional Polyurethane foam which is added in liquid form through a hole in the shrink sleeve. Another hole is drilled in advance, to allow escape of trapped air. The two holes are later closed with fused plugs (Figure 14).

Figure 14. Part of a shrink sleeve around a joint in a 110mm district heating pipeline, containing 2 plugs welded in two holes in the sleeve.



Below: Enlargement of such a plug (yet un-used), upside down. The required fusion zone is at the circumference of the slightly tapered cylindrical part.

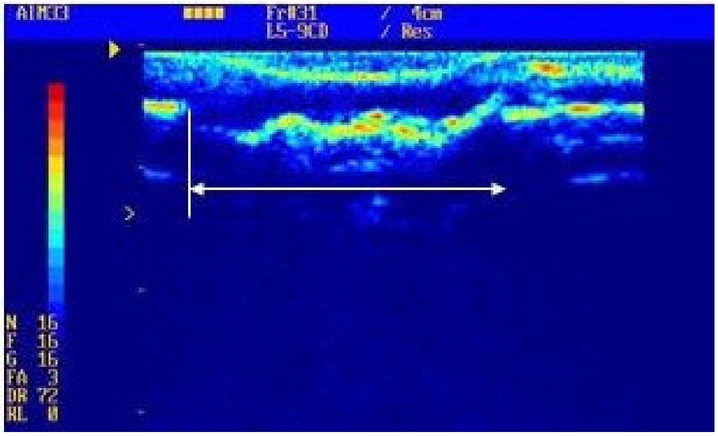


Figure 15. Ultrasonic image of the region around a fused plug, with diameter of about 20 mm (horizontal arrow). Tapered side on the left well-fused, tapered side on the right not well fused.

Some of similar fused plugs in an older district heating system appeared to be leaking due to poor joint quality. This was caused by contamination and poor workmanship.

Figure 15 shows an ultrasonic image of the area around a fused plug. On the right-hand side of the tapered plug a poorly jointed region is visible, which may provide a leak path for ground water. Such leakage may initiate the disastrous chain of events described above.

DISCUSSION

1. Electro-fused joints in PE and PEX pipes

All PEX pipes tested in this investigation were fully cross linked. The electro-fused joints made using all 3 types of PEX pipes described in this paper still met the standard Peel test at 23 °C according to ISO 13954, just as the joint in the PE100 pipe.
Differences in joint quality were only noticeable after long-term testing at 95 °C in the Slow Peel test. This is significant, because one of the most important advantages of PEX pipe with respect to PE pipe is the higher resistance to elevated temperatures. Slow Peel testing shows that electro-fused joints in 2 out of 3 types of PEX pipe demonstrate relatively short times to failure, and the complete peeling off of pipe from the PE100 coupler. The third PEX type provides a higher joint quality: only partial peeling off occurs during almost 500 hours of testing. The best joints are provided with PE100 pipe.
This quality ranking is also found using ultrasonic imaging. This means that ultrasonic imaging can be used to inspect the quality of joints in materials that are slightly more difficult to join than traditional PE materials.

However, the above results do not mean that only one type of PEX pipe is most suitable for applications at elevated temperatures. It is already well-known that very strong fusion joints can be made in crosslinkable PEXb pipes. Such pipes and joints in them – which were not included in the present investigation - are still not cross linked after extrusion, and are only cross linked after jointing. Because the quality of such joints depends on chemical bonds, the joints even remain intact at 150 °C [3, 4, 5], which is 20 °C above the melting point of PEX pipes.
Results published in a confidential report confirm that at 150 °C, which is clearly above the melting point of PEX pipes, a load bearing capacity of butt-fused joints of about 1 MPa can be obtained. Constant Load tests according to the German standard DVS 2203-4 performed on such joints at 95 °C and 5.5 MPa during more than 1244 hours in 2% Arkopal detergent

proved a fusion factor of 90% [6]. This means that the long-term load-bearing capacity of the joints in post-weld cross linked, crosslinkable PEXb pipes is even 90% of that of non-fused, fully cross linked PEXb pipe (6.1 MPa at 95 °C during 1244 hours).

2. PE80 pipe with voids
Ultrasonic inspection also proved successful in detecting voids in poorly produced pipes. Defects smaller than 0.17 mm can be detected. In this case the equipment can be used with success in a factory to check the integrity of produced pipe materials.

3. PE jacket pipe of a district heating system
The ultrasonic equipment is also capable of detecting flaws in a jacket pipe consisting of several layers of foils. The poor pipe quality was confirmed by Constant Load testing.

4. Poor joints in plugs
Other type of joints can also be detected, like joints between slightly tapered plugs used to close holes in a shrink sleeve.

Other imaging techniques
Inspection and imaging techniques which use other types of signals are also known.
One of these techniques uses near infra-red radiation. Portable equipment that can be used on-site is available, but the method of operation is often surface reflection. Carbon black pigment causes severe absorption of the reflected signal. If carbon black pigment is absent, information depths of several millimetres may be reached.
Other equipment uses far infra-red radiation. Some results on polyethylene materials, but no pipes, were published [7, 8, 9]. The type of information obtained on PE is unclear. Most samples originate from the pharmaceutical industry. The instrument is relatively large and is therefore only available as laboratory equipment.
The principle of Nuclear Magnetic Resonance is also used, in mobile equipment denoted the NMR Mouse ®. Many different defects could be visualised [10, 11].
It is still unclear what the advantages and disadvantages of the mentioned inspection techniques are and how they compare.

CONCLUSIONS

1. By using ultrasonic inspection equipment it is possible to perform non-destructive inspection through pipe walls and fusion joints, after production in the factory or in the field, to detect internal defects.
2. The results of ultrasonic inspection of electro-fused joints in PE and PEX pipes correlate with the results of Slow Peel tests, but there is no correlation with the results of standard Peel tests at 23 °C according to ISO 13954. Ultrasonic inspection and the Slow Peel test provide information that is more related to defects that become important after long-term operation at elevated temperatures.
3. The standard Peel test according to ISO 13954 does not detect the differences in joint integrity noted by the Slow Peel tests on and ultrasonic inspection of electro-fused joints in PEX pipes. However it is still possible that the requirements of the standard Peel test are satisfactory for ambient temperature applications.
4. It is proposed to perform a comparison between the different non-destructive inspection and imaging techniques discussed in this contribution, using exactly the same samples.

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