Development and validation of an automated non-destructive evaluation (NDE) approach for testing welded joints in plastic pipes

F Hagglund, M Spicer and M Troughton

A reliable non-destructive evaluation (NDE) approach is required for the inspection of different polyethylene (PE) pipe joints in various material grades and pipe sizes. In February 2010, a European (FP7)-funded project on the development and validation of an automated non-destructive evaluation (NDE) approach for testing welded joints in plastic pipes (TestPEP), involving 13 organisations from seven European countries, was started. Several individual tasks need to be solved before approaching the final solution. The challenging material properties of PE pipes, low speed of sound and high-frequency-dependent attenuation, must be overcome. A flexible scanner with probe and wedge holder incorporated must be adaptable for the variety of pipe joint configurations. Furthermore, a rugged flaw detector instrument will be developed, capable of performing the advanced procedures required for these materials. In this paper, the technical problem, industry needs and the proposed approach to the solution are stated. Initial results show the route for success in the project together with the proposed inspection system and inspection techniques.

1. Introduction

Plastic pipes offer significant advantages over other materials, such as cast iron, steel, copper and concrete, for the transportation of fluids such as natural gas, water, effluent and corrosive liquids. They do not corrode, have a longer predicted service life leading to less frequent replacement, they are less expensive to install due to their light weight and flexibility, and they have significantly lower leakage rates due to having an all-welded system. However, their more widespread use is being restricted by the lack of a reliable NDE method for inspecting the welded joints. Pipeline leakage does not only cause high repair costs but can also result in disastrous environmental consequences.

The TestPEP project will develop phased array ultrasonic NDE procedures, techniques and equipment for the volumetric examination of welded joints in polyethylene (PE) of diameters up to 1 m. A key aim of the project is to develop an inspection system that is site-rugged and simple to operate. Current phased array instruments require ventilation and space, and many have fragile viewing screens. The concept in this project is to have a black box instrument with a simple ethernet connection to download the recorded data, and to provide the necessary robustness of the phased array probe. Another objective of the project is toanalyse the data semi-automatically, so that a red/green (yes/no) answer can be provided and the system can be operated by normal pipe-laying technicians.

The prototype NDE equipment, designed and built as part of this project, will be assessed under both laboratory and field conditions.

2. Technical problem

Although there are European standards for the volumetric inspection of plastic pipe welds, there is a lack of commercially-available systems for inspecting these welds. All large-diameter steel pipes for the transportation of both natural gas and LPG are subject to volumetric inspection. The current best practice for inspection of these steel welds uses ultrasonic phased array NDE. From this evidence it is clear that the plastic pipe industry is out of step and lagging well behind the steel pipe industry. Why are there no inspection systems for plastic pipes? The main reason is because plastic is a difficult material to inspect due to its very specific physical properties of high attenuation and low ultrasonic velocity.

To fully cover the weld inspection area it will be necessary to investigate and solve the challenge of generating angled ultrasonic beams in these highly attenuative materials. In addition, the inspection equipment must be able to withstand the harsh environment in which plastic pipes are often installed and be simple to operate by technicians who are not used to delicate instrumentation.

3. State-of-the-art

The two main techniques for welding plastic pipes are butt fusion welding and electrofusion (EF) welding. In butt fusion welding, see Figure 1, the pipe ends, which have been cut square and flat, are pushed against a heated metal plate until they melt; the plate is then removed and the pipes are pushed together and allowed to cool, forming a weld.

In EF welding, the pipe ends are pushed into either end of the EF fitting, which contains a coil of heating wire in the inside, see Figure 2. Current is passed through the coil, which heats up and melts the inside of the fitting and the outside of the pipes, producing a weld.

The prototype NDE equipment, designed and built as part of this project, will be assessed under both laboratory and field conditions.
3.1 Limitations of current inspection knowledge

- Currently, the only commercial ultrasonic inspection systems for plastic pipes are in North America and South Korea\(^1\). The American system is limited to butt fusion welds and uses conventional time-of-flight-diffraction rather than phased array and, as a consequence, it is not applicable for more complex weld configurations such as elbows, reducers and tees. The Korean system is limited to electrofusion joints and does not record data.

- Within Europe there are no volumetric inspection systems and the reliance is upon visual inspection and mechanical testing.

- TWI has developed inspection technology with reporting criteria for some sizes of PE pipe but there is no commercial system available.

- There are currently no commercially available compact and sealed phased array instruments.

- The available phased array probes are expensive and mechanically vulnerable due to the cabling.

4. The proposed solution

The TestPEP project seeks to develop effective phased array ultrasonic NDE procedures, techniques and equipment for the volumetric examination of pipe-to-pipe and pipe-to-fitting (elbows, bends, reducers, tees) butt and socket joints in various PE pipe materials with diameters between 90 and 1000 mm, and to determine the significance of flaw types and sizes in relation to service requirements. This will lead to a longer average service life of plastic pipe systems and lower leakage rates, resulting in reduced risk of serious accidents and pollution, which in turn will lead to significant economic benefits as more widespread use of these materials occurs.

The ultrasonic system developed will be sufficiently rugged to be able to operate in harsh environments, as can be seen in Figure 3. Furthermore, it must be easy to operate and will solve the very challenging technical problems of ultrasound transmission into plastic. Phased array probes can collect ultrasound data very rapidly and the inspection will be performed with a single pass around the weld without any mechanical axial movement. This simplified mechanical concept will solve many of the required economic and ergonomic challenges. The ultrasonic instrument will be a black box, with no ventilation holes and a simple ethernet connection to download the recorded data and to provide the necessary robustness for the harsh environment in which plastic pipes are often installed. In addition, the inspection system will provide a simple pass/fail output so that it can be deployed economically by normal pipe-laying teams. This development will require flaw analysis algorithms to be implanted into the instrument.
level enabling new and more demanding applications of plastic pipes.

- A database of critical defect sizes and contamination levels that cause a reduction in the long-term integrity of each of these types of welded joint.
- An ultrasonic phased array system for the reliable volumetric examination of plastic pipe joints and fittings during their installation or retrospectively.
- Automatic defect sentencing software to enable a pass/fail indication for the inspected weld.

5.2 The technical deliverables will include:

- Expanding the basic inspection technique to a range of PE materials and fitting types used in the industry.
- A new compact phased array flaw detector with the ability to drive phased array probes in a harsh compact environment.
- An integrated scanner and phased array probes providing a rugged system.
- Novel data analysis and processing software enabling the system to be used rapidly in the field by pipe-laying technicians.
- Inspection procedures including flaw reporting criteria and flaw acceptance levels.
- Rugged phased array sensor design that is adaptable for many materials and fitting types.
- Awareness programme for managers in SME inspection service providers, pipe welding equipment suppliers and pipe-laying equipment companies.
- Guidelines for application and operator training and certification, leading to future standards.
- Training programmes in phased array inspection technology.

6. Approach and initial results

The development will be made by manufacturing welded joints containing known flaws. The NDE data will be analysed to determine the limits of flaw detection for each technique. In parallel, the significance of flaw size and quantity will be established in relation to service requirements. This will be achieved by long-term mechanical testing of joints containing known flaws, and comparison with results for welds containing no flaws.

A combination of different NDE techniques will be used to achieve full coverage of each joint configuration. The instrument and processor will be able to drive all techniques simultaneously and, using embedded automatic defect recognition algorithms, deliver a yes/no result to the operator. The instrument will be positioned on the scanner with an incorporated probe holder, see Figure 4.

6.1 The inspection techniques

For inspecting EF joints, the challenge is to achieve a resolution good enough to be able to inspect the fusion zone beyond the heating wires. Careful parameter choices for the phased array probe are important. Since the attenuation increases rapidly with frequency in plastic materials, the most appropriate solution is a compromise; the frequency must be low enough to enable the sound to propagate the required distance and high enough to achieve the desired resolution. This problem is approached by using a normal linear scan focused at the fusion zone, see Figure 5.

Inspecting butt fusion joints requires different techniques. Angled ultrasound is required and a combination of different techniques is necessary to obtain full coverage. Phased array implemented time-of-flight diffraction (TOFD) will be used for inspecting the majority of the fusion zone. A developed phased array self-tandem technique will be used to detect planar flaws in the middle of the fusion zone, and the top part of the fusion zone will be targeted with creeping waves. The combination of these techniques, Figure 6, has been shown to achieve the desired defect detection level.

7. Conclusions

In this study, it has been concluded that different techniques are required to inspect the different joints and to achieve full coverage of the fusion zones. Furthermore, a water wedge is used to minimise the loss in energy due to attenuation and to achieve the velocity mismatch at the pipe surface to be able to produce the angled beams required.
Acknowledgements
The TestPEP consortium is made up of several organisations from several European countries. The research leading to these results has received funding from the European Union’s Seventh Framework Programme managed by REA-Research Executive Agency ([FP7/2007-2013] [FP7/2007-2011]) under grant agreement no 243791.

References

© TWI

Order online at www.bindt.org

Materials Testing 2011
Telford International Centre, Telford, UK
The Place to Meet and Do Business
The international exhibition for all concerned with NDT, testing for quality, materials testing, condition monitoring and diagnostic engineering.

The Institute’s Annual Conference, NDT 2011, is to run alongside the Materials Testing Exhibition, giving delegates many opportunities to visit the show.

Cost-effective participation packages are available.

Materials Testing 2011 will present companies with a major forum for promoting their products and services and interfacing with their markets;

a unique opportunity to: review the latest technologies ● source new contacts ● meet industry colleagues keep up-to-date ● get new business ● participate in the development of the industry.

Organised by The British Institute of NDT
Newton Building, St George’s Avenue, Northampton NN2 6JB, UK.
Telephone: +44 (0)1604 89 3811; Facsimile: +44 (0)1604 89 3861
E-mail: mt2011@bindt.org

www.materialtesting.org

Ultrasonic Flaw Detection for Technicians, 3rd Edition
by J C Drury

In the twenty-five or so years since the first edition of ‘Ultrasonic Flaw Detection for Technicians’ was published, there have been a number of advances in transducer technology and flaw detection instruments. The gradual acceptance by industry that the sizing of weld defects by intensity drop was not as accurate as had been claimed led to the development of the TOFD technique. Modern digital flaw detectors and computer technology allow far more information to be stored by the operator. The author thus felt that it was time to give the book a thorough review and to try to address some of the advances. The result is this new edition.

Available price £25.00 (Non-Members); £22.50 (BINDT Members) from The British Institute of Non-Destructive Testing, Newton Building, St George’s Avenue, Northampton NN2 6JB, UK. Tel: +44 (0)1604 89 3811; Fax: +44 (0)1604 89 3861; Email: info@bindt.org

Order online at www.bindt.org