THE INSPECTION OF COLD WELDS IN ELECTROFUSION JOINTS

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ABSTRACT

Electrofusion joints for polyethylene pipe are one of the common joining methods used in the water and gas industries for distribution pipelines. Common problems in manufacture of these joints are contamination, lack of fusion, lack of penetration and insufficient heat applied to the joint. The latter flaws can result in a joint that, although apparently fused, does not have the same mechanical properties as a properly prepared joint.

This paper presents ultrasonic and thermal techniques for detecting and monitoring flaws in the weld. For post welding application a phased array ultrasonic technique is described that indicates flaws at the weld joint and the size of the heat affected zone as a record of the applied heat.

Results of laboratory experiments on sample pipes are described, and prototype systems for application of the techniques to site work are also shown.

1. INTRODUCTION

As for all welding processes, if incorrectly designed or controlled, welding defects can be generated. As electrofusion is a relatively simple process, once the process has been designed and tested, defect production should be rare but incorrect application of the process including incorrect joint preparation can affect the quality of the weld. For this reason, good NDT to aid the quality control process is required.

This paper is based upon a project "Polytec"™ and TWI exploratory work for the in-manufacture quality control of polyethylene electrofusion joints. Polytec is a collaborative project lead by TWI with co-industrial partners Vermont, Isotest, NDT Consultants, Horton Levi and also Italgas, N.W. Water, Simplast, Egeplast, Catania Ricerche, Northumbria Water and Hessel Ingenierthecnik. The object of the project was to develop an on-line method for determining the quality of electrofusion joints and their fitness for purpose. The industrial interest in Polytec guided the project towards the essential requirements of the inspection methodologies.

Two quality control inspection methodologies were developed in this project along with correlation results between manufacturing flaws and mechanical properties of the joints. The two NDT methods are ultrasonic phased array and a thermal monitoring method. Both methods were capable of finding the majority of manufacturing faults. Further there was some indication that the thermal method may have a better capability for the detection of incorrectly scraped joints but the ultrasonic method in general appeared to be more robust an inspection system as discussed later.

This paper concentrates on the ultrasonic phased array method developed for the inspection. Some results from the thermal method are also presented.

The ultrasonic techniques described in this paper detect conventional defects and supplies a method for determining whether the weld has been correctly welded by monitoring the position of the heat effected zone.

2. ELECTROFUSION JOINT WELDING PROCESS

The application of the electrofusion process is shown in Figure 1. The pipes are inserted into the coupler and an electric current is passed through a heating element in the coupler, causing the plastic of the pipe and coupler to melt and fuse.

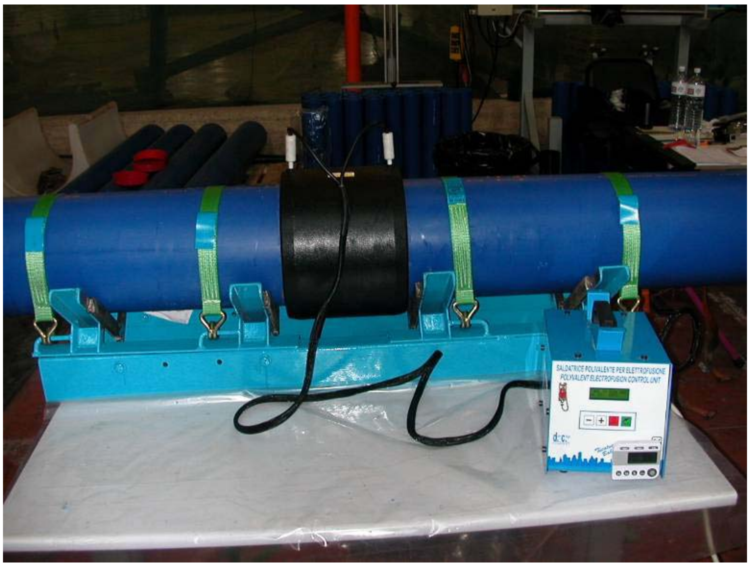


Figure 1. Electrofusion equipment and weld production

The flaws that might occur are:

1) **Void**. This is a flaw that is totally subsurface, volumetric (not planar) and contains no material.
2) **Lack of fusion.** This flaw is the unfused mating surface of the pipe and the coupling.
3) **Incorrect heating cycle.** This flaw results in a weak joint due to the incorrect crystallographic structure of the joint.
4) **Incorrect pipe cleaning.** This flaw results in a weak joint due to incomplete fusion but does not result in a lack of fusion flaw. Lack of cleaning includes lack of scraping.

Figure 2 shows the location of potential flaws.

3. DEVELOPMENT STRATEGY

3.1. Introduction

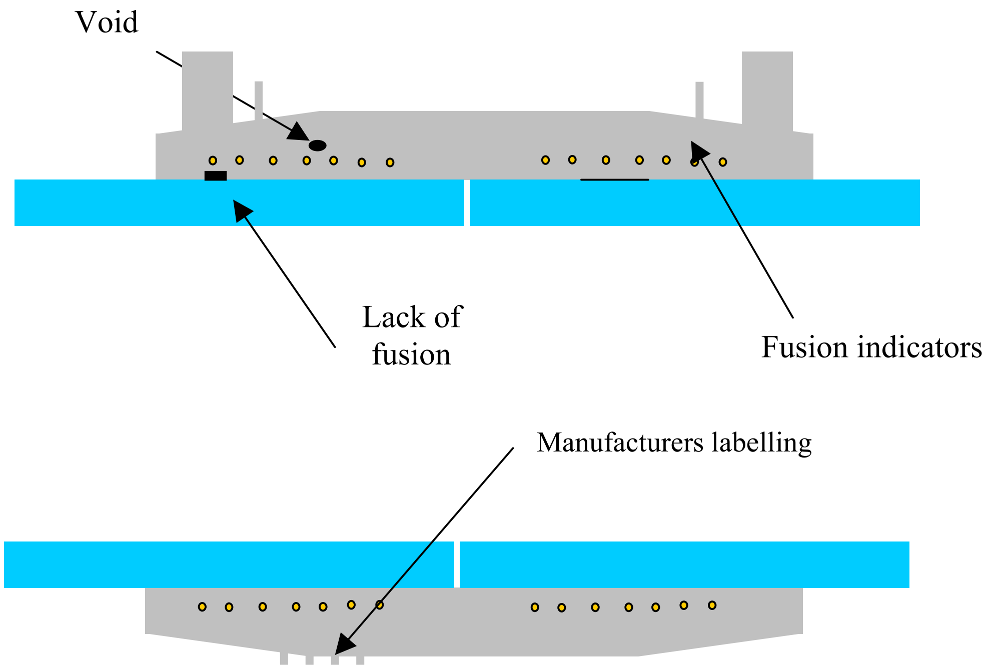


Figure 2. General construction and location of joint flaws.

From previous published work and discussions with the water and oil and gas industries it was clear that both voids and lack of fusion needed to be detected and that the inspection time needed to be a minimum. Further a permanent record of the inspection results was required if quality assurance requirements were to be fulfilled.

The work of TWI concentrates on industrial application of NDT methods. The emphasis of the development was on the rapid inspection of the electrofusion joints in field conditions.

3.2. Inspection Challenges

Figure 2 provides a cross section view through a coupling. It shows the position of the heating wires and possible flaw locations. The external varying shape of the coupler and the external protrusions e.g. labelling and fusion indicators are obstructions to the passage of an ultrasonic probe for inspection. In addition, there is a different coupling design for every different manufacturer and operating pressure rating for the pipe and joint.

From these considerations it was concluded that a contact inspection would not be feasible and an immersion inspection was required.

A further consideration was the location of the lack of fusion flaws. The only access for inspection was the external surface of the coupler. Lack of fusion defects are then “behind” the wires with respect to the ultrasonic probe. The wires have diameters ranging from 0.6 to 1.7mm with a similar separation. To resolve defects from the wires a tightly focused ultrasonic beam was required.

For the above reasons an immersion phased array ultrasonic inspection was believed to be and proved to be a suitable method of applying focused ultrasonic beams to the components whilst maintaining full sensitivity and accommodating the varying surface conditions.

Additionally a thermal method was developed with the placement of thermocouples onto the outside of the pipe and coupler.

3.3. Development Welds

To develop inspection methods, defects of a known size are required. In the field, planar flaws can be produced by, for example, air pockets, water, grease and fingerprints. Previous work at TWI has shown that, for ultrasonic NDT, a good simulation of planar flaws are thin aluminium discs. A selection of thin (0.025mm) aluminium discs of various sizes (4, 8, 15, 25mm diameter), were inserted into the joint.

Further joints were manufactured with incorrect heating cycles, incorrect surface preparation and surface contamination simulating incorrect cleaning.

In total over 80 welds were produced to evaluate the ultrasonic performance from both 125 and 250mm diameter pipes. The majority of these welds have been subject to mechanical testing after the ultrasonic examination. The mechanical tests are a subject of further papers.

4. DEVELOPMENT RESULTS

The development results are divided into six sections:

- Ultrasonic velocity measurements and attenuation measurements
- Manipulator design
- Ultrasonic phased array probe design
- Defect detection results
- Heat effected zone location
- Thermal results

4.1. Ultrasonic Velocity and Attenuation Measurements

The longitudinal velocity of ultrasound at 20° C was measured to be 2220m/s.

An important factor for this inspection was the elapsed time before the ultrasonic properties of the weld were stable enough to provide a reliable inspection.

As an example the velocity and attenuation results for a 250mm diameter pipe is given. The joint velocity after 75minutes was 1730ms^{-1} with a loss of 15dB signal strength compared with that of the sensitivity at 20°C. It must be noted that the measurements are interface temperature measurements rather than the average temperature for the total sound path. For this reason even when the apparent temperature has reduced the attenuation and velocity measurements are greatly changed from ambient due to the volume of high temperature material increasing with time. From these experiments it was concluded that the 250mm diameter coupling could not be inspected before 2 hours after the heating cycle and the 125mm couplings before 1 hour after the heating cycle. Other designs and sizes of coupling were tested to find that every design and size required very different cooling times.

4.2. Phased Array Probe Design

TWI has used a probe modelling package for the specification of the phased array probes. This package enables the positions of the diffraction grating side lobes to be calculated and the amplitude of these relative to the main beam to be predicted.

As introduced in the discussion section of this report the aim of the inspection was to provide a single pass inspection of the coupling. To achieve the required resolution and detection of the pipe ID a frequency of 7MHz was required for the 125mm diameter pipes and a frequency of 5MHz for the 250mm diameter pipes. The smaller the probe elements the less interference the side lobes create but the smaller the probe elements the more elements are required to provide inspection of the full length of the fusion zone of the coupling. Commercial phased array instruments are generally limited to a maximum drive capacity of 128 elements. Also the more elements that are required the more expensive the inspection system becomes. From all these considerations the best compromise between element size, signal to noise and inspection length was produced. The final probe specification for the 125mm diameter pipe joints was a 7MHz probe with 0.6mm element pitch with a mechanical focus in the circumferential direction to maintain a circular focal spot on the curved cylindrical surface. This has produced a phased array probe with a 0.4mm focal spot at the coupling fusion face enabling resolution of the wires and flaws.

4.3. Ultrasonic Manipulator Design

The manipulator shown in Figure 3 was developed to deploy the phased array probe, record the probe position and maintain ultrasonic coupling. The photograph shows the water supply to the probe pan and the brushes used to minimise the water loss. The inspection requires the scanner to be rotated around the coupling once for each end of the pipe. The manipulator has been designed to accommodate pipes ranging from 125mm diameter to 250mm diameter for Agru and Fusamatic coupling designs.

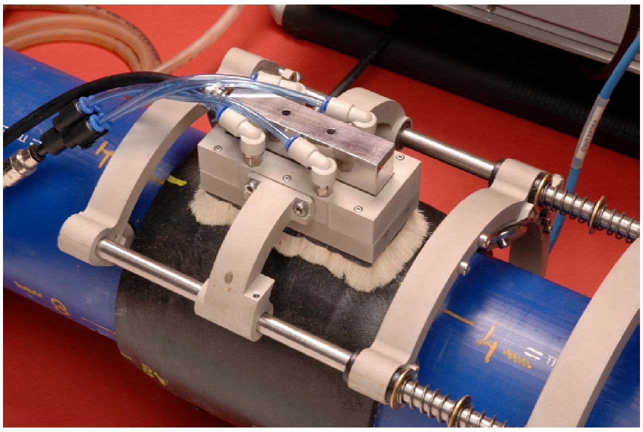
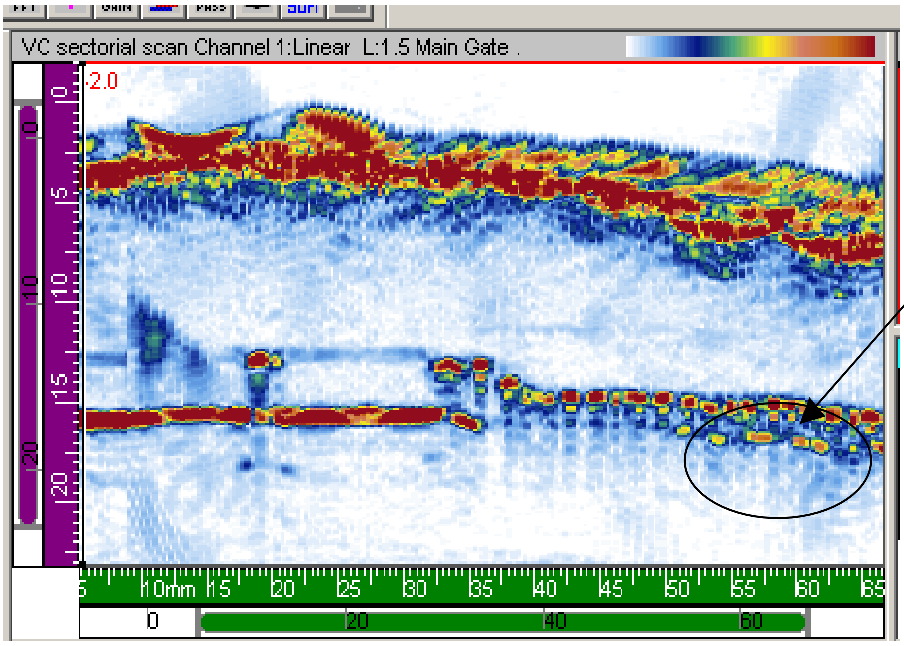


Figure 3. Photograph of inspection manipulator

4.4. Ultrasonic Flaw Detection

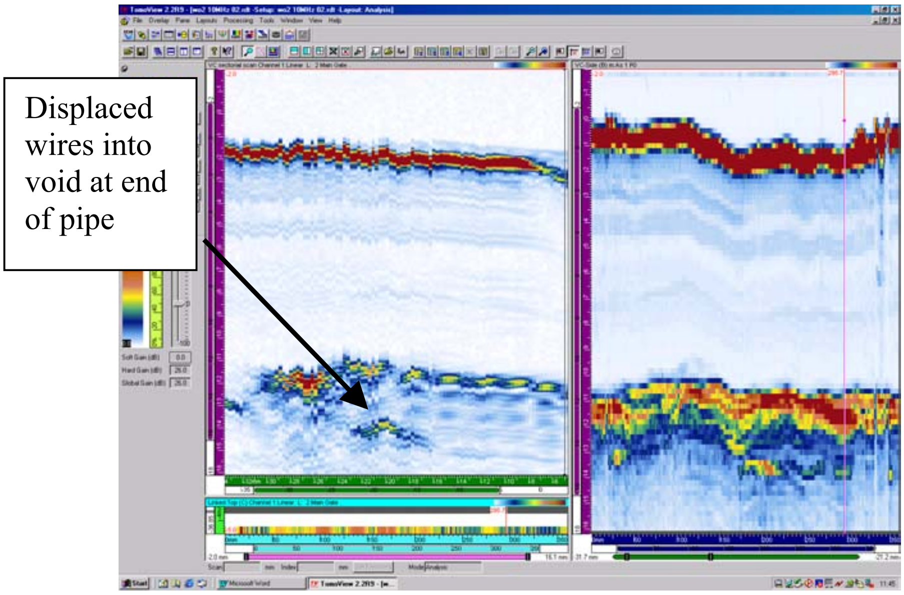
From all the trials it was concluded that lack of fusion defects with a diameter of 4 mm could be reliable detected in all the joint configurations inspected. An example of an ultrasonic image is given in Figure 4. This shows detection of a 4mm diameter lack of fusion.

In addition to lack of fusion defects along the pipe interface. Figure 5 shows displaced wires that often occur when there is lack of penetration of the pipe.



LOF caused by grease

Figure 4. Phased array data showing lack of fusion defects caused by grease contamination



Displaced wires into void at end of pipe

Figure 5. Pipe with lack of penetration

The flaws shown in figures 4 and 5 require conventional ultrasonic amplitude for detection. A serious flaw in electrofusion joints can be produced from incorrect and insufficient heating. This flaw can result in a weak joint without conventional lack of fusion. Figure 6 provides a section through a joint showing the heating wires and the correct position of the Heat Affected Zone (HAZ).

Figure 7 shows images of a correctly heated joint and a joint with insufficient heating. The images show the positions of the HAZ and the closer proximity of the HAZ to the wires for the insufficient heat input joint.

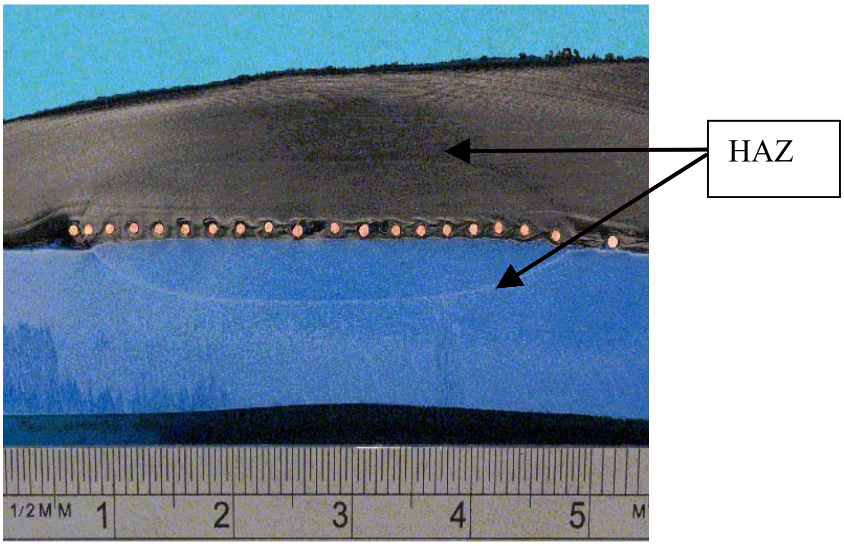


Figure 6. Section through pipe showing heating wires and Heat Effected Zone (HAZ)

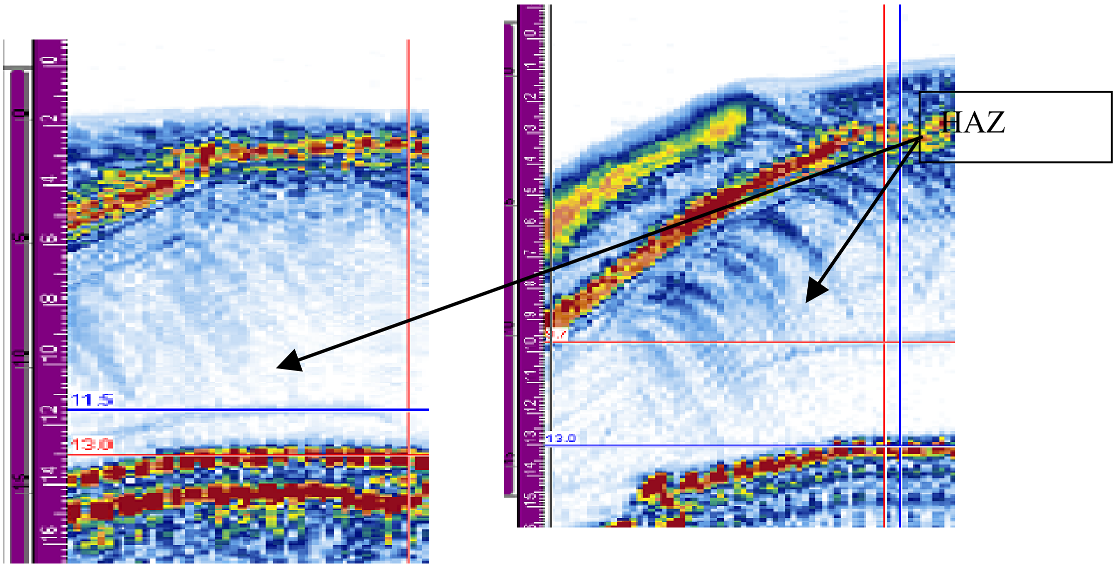


Figure 7. Comparison of welds with full and short heating cycles showing reduced HAZ.

A correlation has been established between the physical measurement of the HAZ and the results obtain ultrasonically. These results are shown on the following Figure 8

This chart shows good correlation between the two results, the phased array inspection method providing an accurate and reliable measurement of the HAZ position and diagnosis of an incorrect heating cycle.

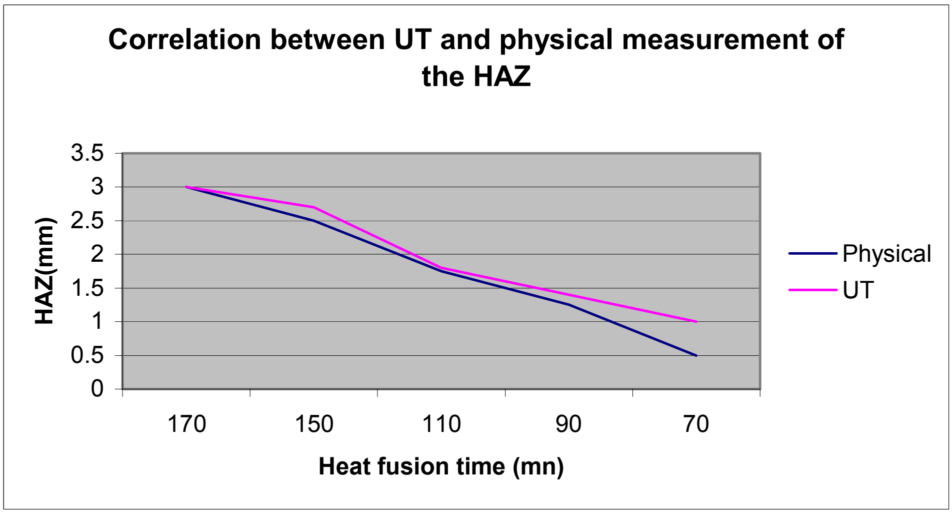


Figure 8: Correlation between the physical measurement of the HAZ and the value obtain with the phased array ultrasonic inspection.

4.5. Thermal Measurements

As introduced the project developed a thermal inspection system which place thermocouples onto the joint and measured the temperature change with respect to time during the welding stage and during reheat. Figure 8 shows the location of the thermocouples. This method can easily monitor and provide a permanent record that the correct heating cycle has been applied and provides evidence of any heating cycle anomalies.

Figures 9 and 10 provide examples of the thermal measurements. In both cases the black lines represent the thermal history of fully fused good joints and the red line shows the time history of a faulty joint. In both cases the temperature curve of the faulty joint was lower than that of the reference good joints. More trials are required to determine the error bands of the thermal history before flaw detection claims are made.

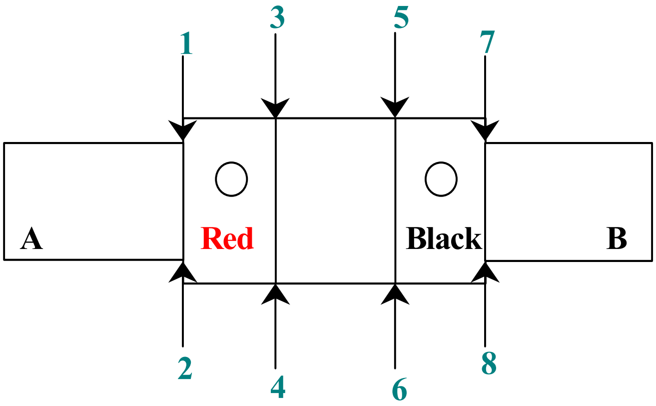


Figure 8. Positioning of thermocouples on coupler

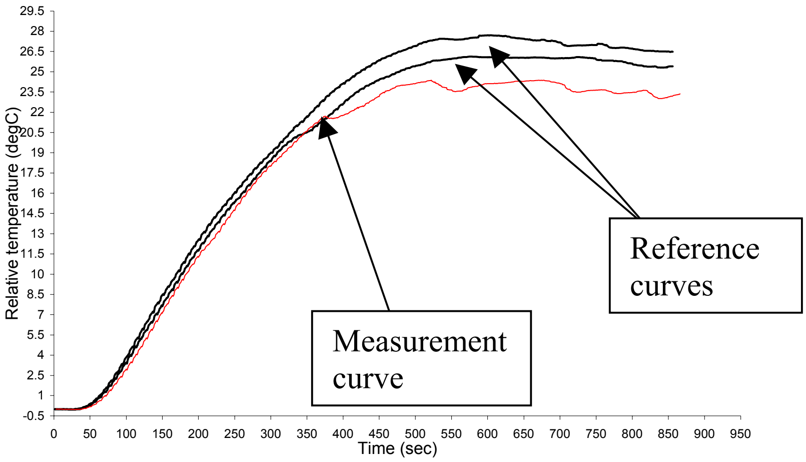


Figure 9. Thermal inspection results comparing fully fused full penetration reference joints and a measured joint with lack of penetration

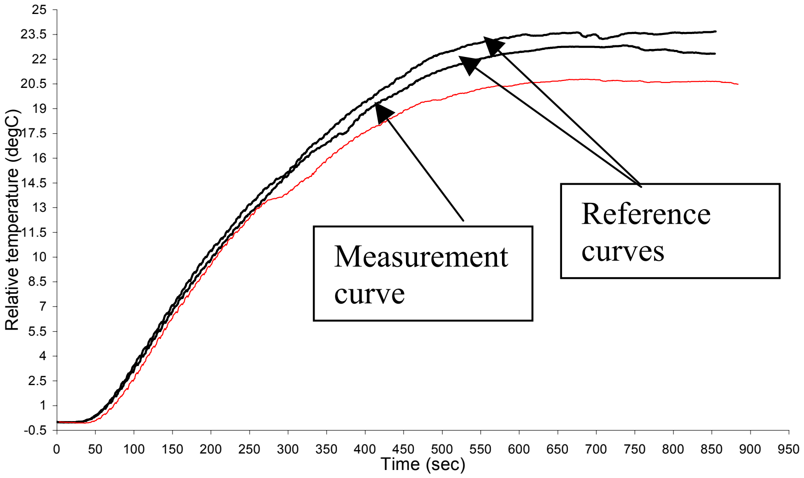


Figure 10. Thermal inspection results comparing fully fused full penetration reference joint and a joint with with a pipe end which has not been scraped

It is believed that the thermal inspection method may provide a complementary method to that of the ultrasonic system and has the advantage of being less expensive than the ultrasonic inspection.

5. DEMONSTRATION OF INSPECTION SYSTEM

The system was demonstrated both at TWI and at Italgas in Italy. Figure 11 shows the equipment performing an inspection of a new 125mm gas pipe at TWI. The prototype demonstrated at Italgas proved to be easily deployed under site conditions with effective defect detection capability for the majority of defects. The existing ultrasonic techniques were not as effective for detection of lack of pipe scraping but the thermal inspection showed some difference between the scraped and un-scraped pipes as shown in Figure 10. More trials are required with the thermal inspection system before a conclusion is reached about its defect detection reliability. At present it is not clear whether un-scraped pipes fail in service. Using a pressure tests this defect has not shown reduced strength in the whole joint. Crush tests however show reduced mechanical strength.

Figure 11 Prototype of ultrasonic inspection manipulator operated in field conditions at TWI.

For both the ultrasonic and the thermal methods the individual designs of the couplers are required before the detailed site inspection procedures can be finalised. The ultrasonic method requires knowledge of the surface profile for manufacture the water seals and to programme the correct ultrasonic parameters. The thermal method requires a set of "good" welds as a reference set for each design of coupler. Further the surface profile knowledge is required for the correct placement of the thermocouples.

6. CONCLUSIONS

1) An ultrasonic method has been developed for the reliable detection of lack of fusion lack of penetration and voids in electrofusion joints.
2) An ultrasonic method has been developed to image the HAZ and determine whether the correct heating cycle has been applied to the joint.
3) A thermal method has been developed which may provide a complementary inspection to that of the ultrasonic system.

7. ACKNOWLEDGEMENTS

1) The EC for part funding the project.
2) Business partners in the Polytec project, Vermont, Isotest, NDT Consultants, Horton Levi, Italgas, N.W. Water, Simplast, Egeplast, Catonia Rerche, Northumbria Water and Hessel Ingeniertechnik.

8. REFERENCES

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