On-line flaw growth monitoring in high temperature plant

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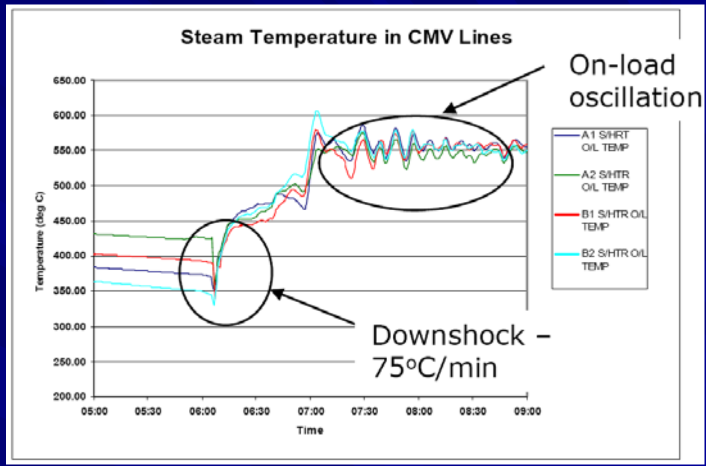
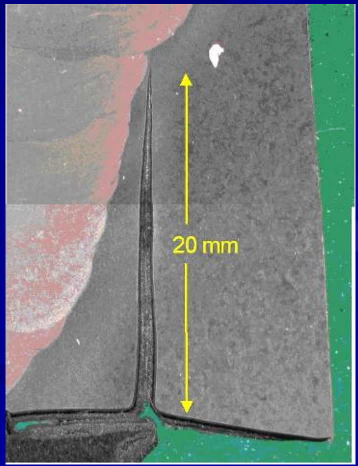
Introduction

- This presentation reports the results of laboratory trials to demonstrate the feasibility of measuring fatigue crack growth in thick-wall steel pipe at temperatures around 600°C.
- This was part of a programme of tests to verify the viability of recently developed high-temperature transducers and associated measurement techniques, prior to a trial on operational plant later this year.

Background

- Operational demands on power plants, especially in commercial markets, can lead to degradation
  - fatigue damage due to thermal cycling
  - creep damage due to thermal transients.
- Because in-service degradation is expected, NDT is performed to provide information that can be used to guide plant operation and maintenance activities.





Background

- When in-service flaws are discovered it is not always feasible, desirable, or necessary to perform immediate repairs or replacement.
- However, there will generally be a need to determine if the flaw is growing, and if so, at what rate, so that remaining life to be estimated.
- In steel components, periodic ultrasonic testing is the preferred method for obtaining quantitative measurements of flaw growth.

Background

- Periodic inspection, especially on high-temperature plant, has a number of commercial and technical drawbacks.
- Commercial
  - Loss of production (including ‘cooling time’)
  - Preparation costs (scaffolding, stripping lagging)
  - Inspection costs (equipment, specialist services, qualification)
  - Reinstatement costs
- Technical
  - Limited accuracy (if flaw growth is less than the measurement error, flaws can appear to ‘grow’ or ‘shrink’ between measurements even if stable).
  - Flaws may be more difficult to detect and size at ambient temperature.
  - Cooling for inspection, and subsequent reheating may increase the degradation being monitored.

Background

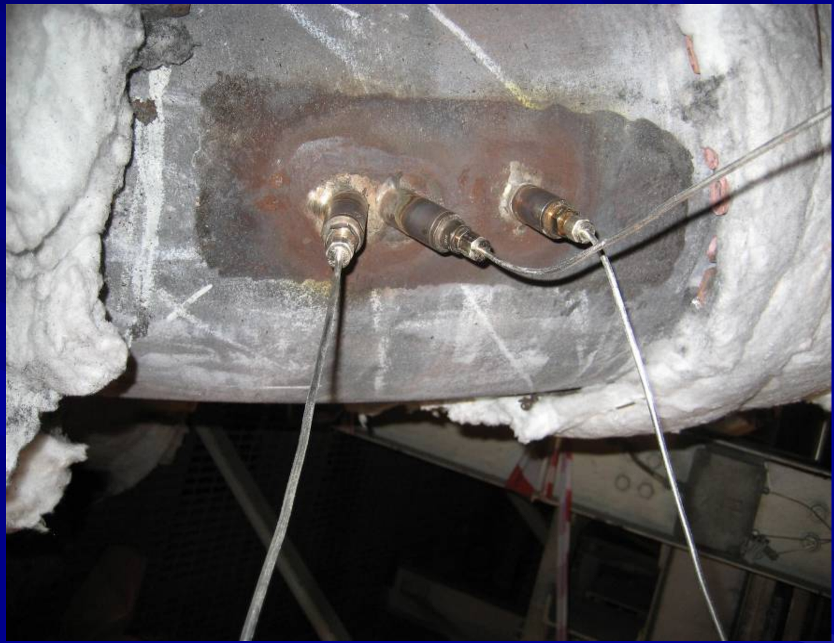
- High temperature in-situ monitoring with permanently mounted probes would avoid or reduce some of these problems.
  – Continuous access to flaw size information avoids the need for periodic shut-down to measure flaw growth, giving greater plant availability and could provide better information on when, and under what conditions, degradation occurs.
  – Greater accuracy is achievable because variations in set-up are avoided, enabling more accurate lifetime prediction.
  – Flaws can be assessed under load.

Background

- Until recently it has not been feasible to perform long-term ultrasonic monitoring at the temperatures found in operational power plant, due to the lack of suitable transducers.
- But over the past eight years, KANDE has been working to develop robust, high-temperature transducers and since 2004 has been collaborating with Doosan Babcock and E.On to develop installation and measurement techniques that make it possible to monitor the growth of fatigue cracks in thick-walled steel components at temperatures around 600°C.

Background

- The work reported here was part of an experimental programme to verify the feasibility of the installation and measurement techniques at high temperature, and followed on from earlier laboratory and site trials.
  - Prototype probes were installed on a steam pipe at an E.ON plant in September 2007 and are still operating.

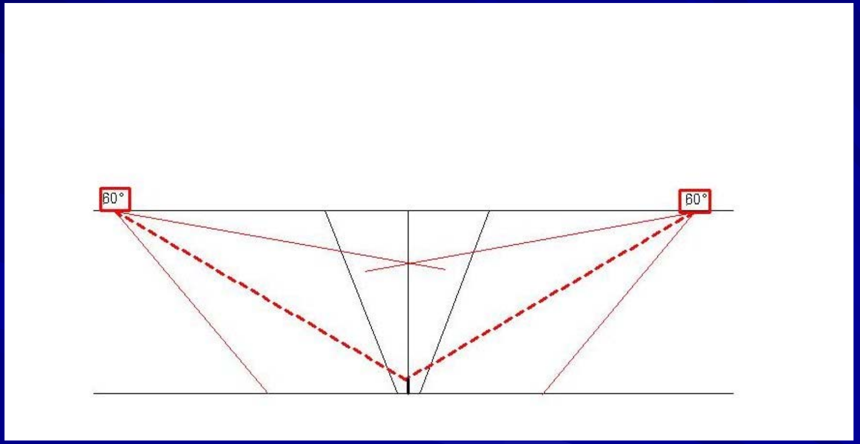


Ultrasonic Probes

- The probes developed for high temperature monitoring use a piezo-electric element with a Curie Temperature >800°C, making them suitable for long-term use at the required operating temperature. The element is bonded to a short steel stud and connection to the probe is made using a semi-rigid mineral insulated co-axial cable.
  - The probes used in the trial had elements 6.35mm in diameter and a resonant frequency of 5MHz.
  - The steel stud was made from 2¼Cr steel to match the pipe material and minimise interface losses.

Measurement Technique

- Crack growth monitoring is performed using a variation of the Time-of-Flight Diffraction (TOFD) technique.
  - This uses two angled compression beam probes positioned either side of the crack.
  - Signals diffracted from the crack tip are recorded and the change in travel time resulting from the growth of the crack causes a change in position of the crack tip signal, which allows the growth to be measured.



Probe Mounting

- Piezo-electric ultrasonic transducers require a coupling medium to transmit the ultrasonic wave between the transducer and the component.
  - In conventional (low temperature) inspection, liquid or gel couplants are used but these are not suitable for high temperature use.
  - There are specialist high-temperature couplants that are designed to work at the temperatures used in this experiment, but these are only suitable for very short term use.
  - Permanent attachment requires the use of methods such as welding or brazing.

Probe Mounting

- For the present application the preferred probe attachment method is by welding.
  - Because the ultrasonic velocities in the probe, the weld and the pipe are the same, there is no refraction of sound at the interfaces, and the required beam angle is generated simply by welding the probe at that angle.
- But as welding close to a known flaw could result in increased crack growth rates, it is important to use pre and post-weld heat treatments to minimise this risk.

Probe Mounting

- As the heat treatment temperatures required in the planned application are high enough to possibly cause some degradation of the probes, pads of weld material are applied to the pipe surface and heat treated.
- The probes are then welded onto these pads without the need for further heat treatment, as the heat affected zone of the probe attachment weld does not penetrate the pipe material.

Experimental Arrangement

- A section of a main steam pipe removed from power plant service was prepared with a circumferential starter notch at the mid position.
- Weld pads were deposited at the positions were the probes were to be mounted.

Experimental Arrangement

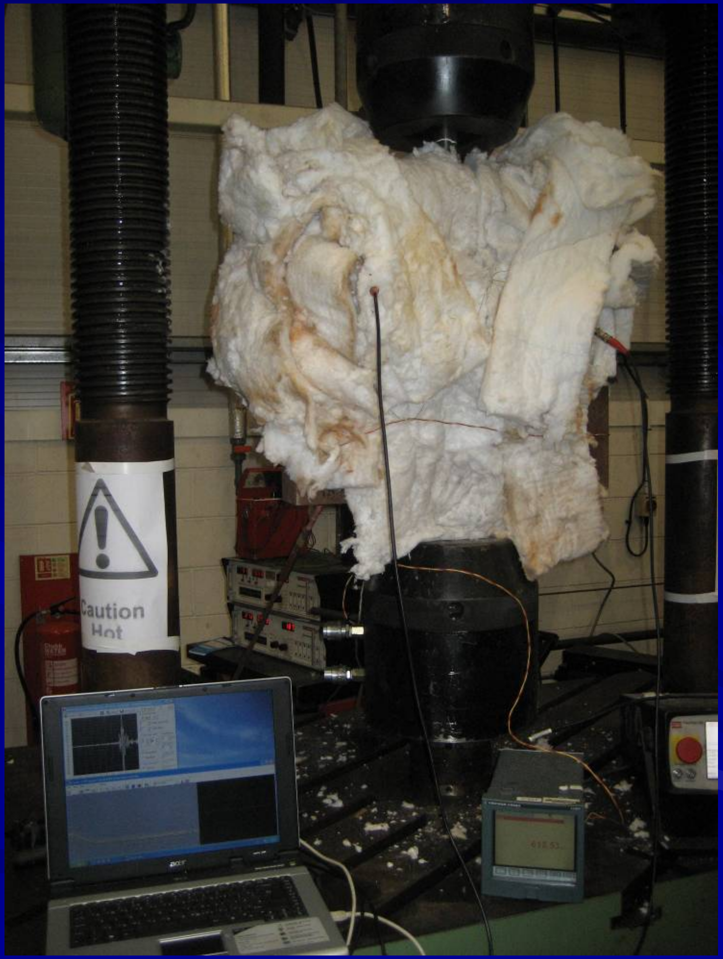
- Probes were welded onto the pads with a beam angle of 45° and a probe separation of ~100mm so as to maximise the response at ~15mm from the inner surface of the 65mm thick pipe.

Experimental Arrangement

- The specimen was mounted in a 4-point bend arrangement in a 600kN tensile testing machine.
- A resistance heating element wrapped around the specimen and mineral wool insulation applied to minimize cooling.

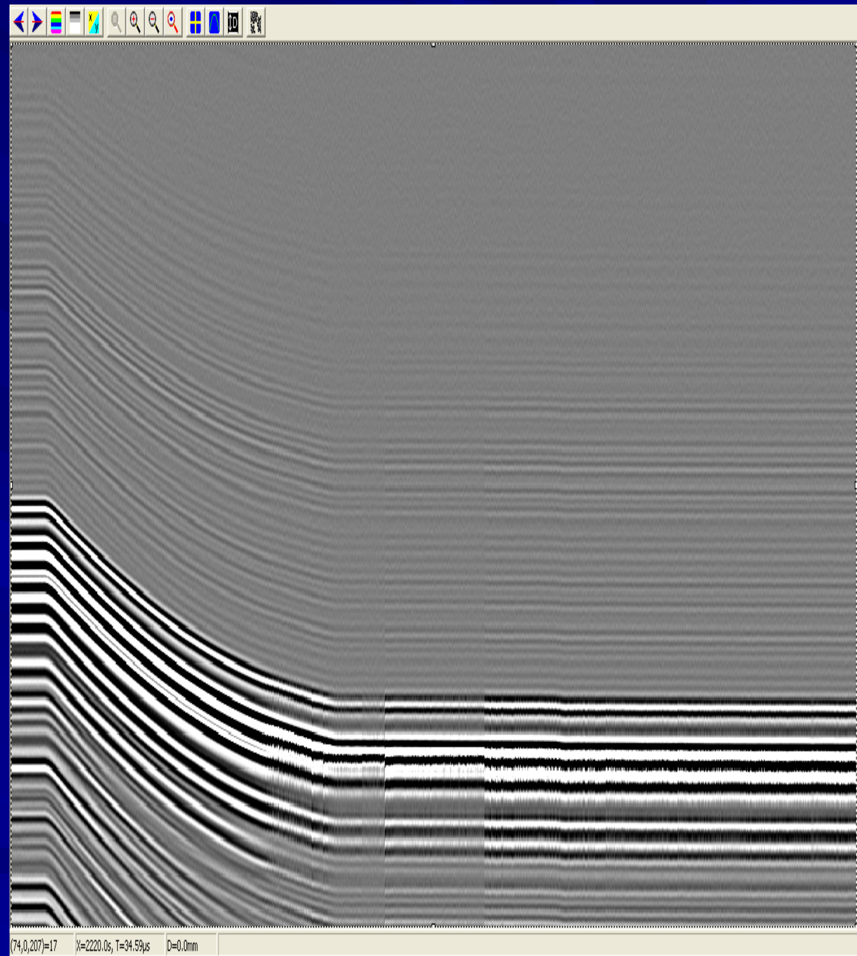
Experimental Arrangement

- UT data were collected using a USBox UT system running monitoring software developed by KANDE.
- This allows A-scan signals to be collected periodically over an extended period and displays them as a TOFD B-scan image.



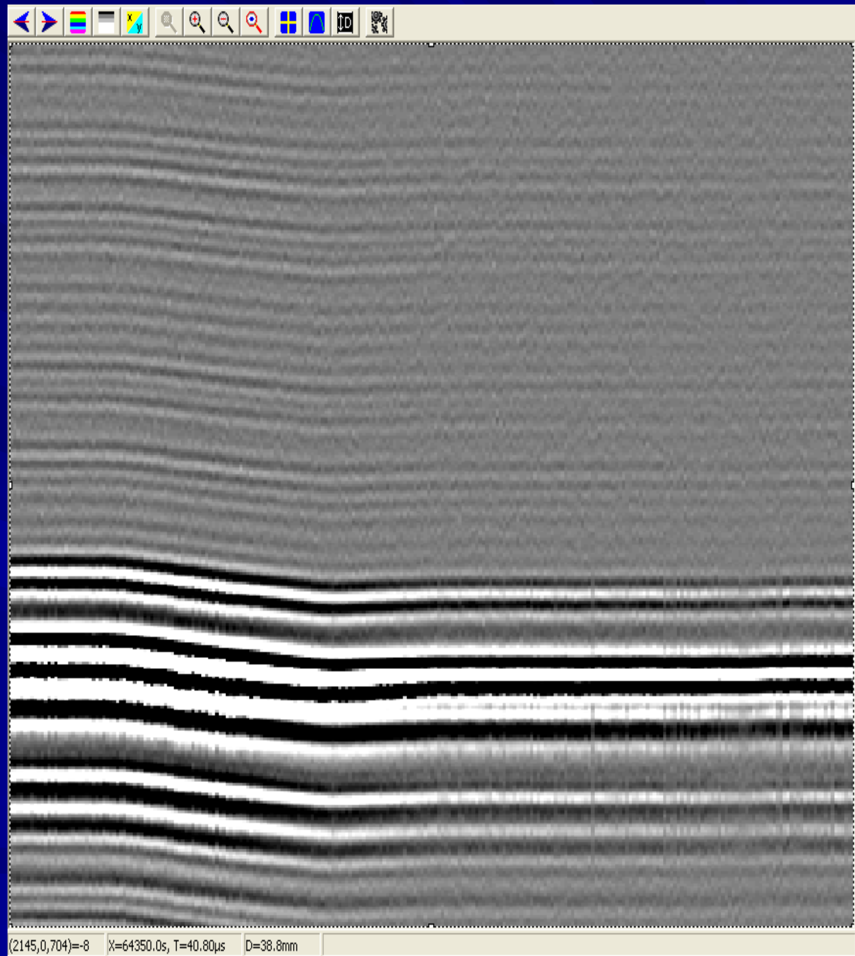
Experiment

- The specimen was heated from ambient temperature to 585°C and held at this temperature overnight without cyclic loading
  - UT A-scans were recorded every 30sec to build up the TOFD ‘B-scan’ image over the course of the trial.



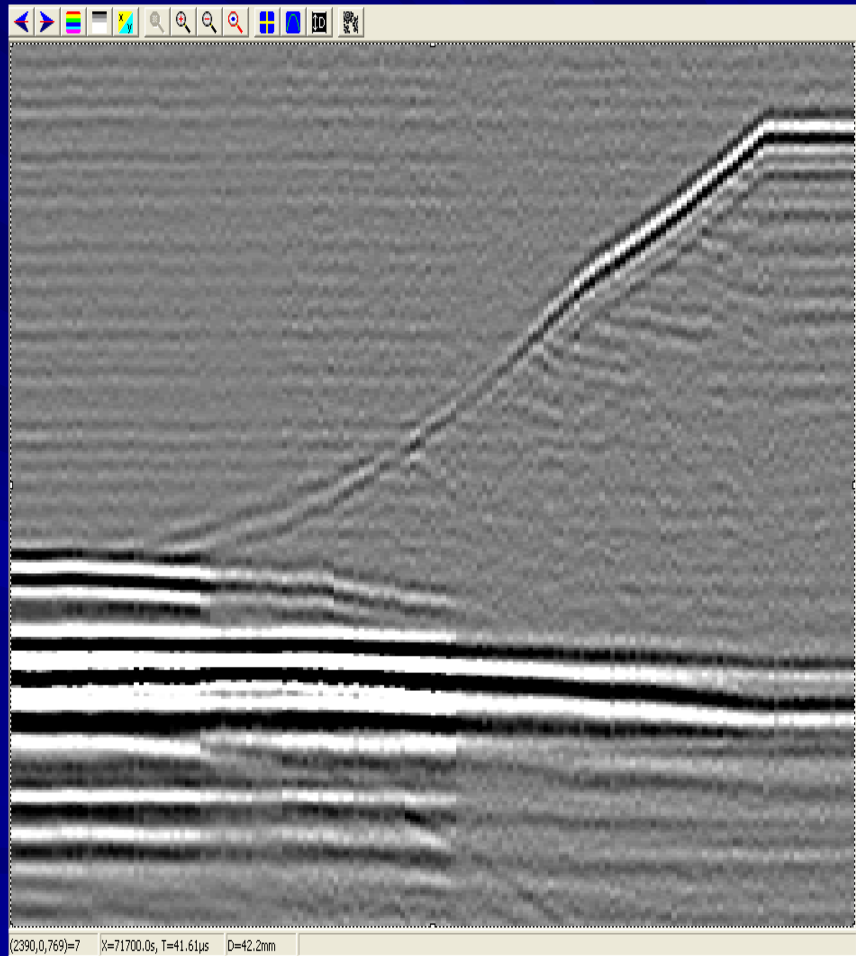
Experiment

- The following morning, the temperature was increased to 615°C and allowed to stabilise before cyclic loading was started.
  - The shift in signal position due to the change in velocity due to the 30°C temperature rise is easily seen.



Experiment

- A short time after cyclic loading was started, changes of signal were observed.
  - The rate of growth increased steadily until the applied load was first reduced and then cycling stopped, with the specimen held at 615°C.



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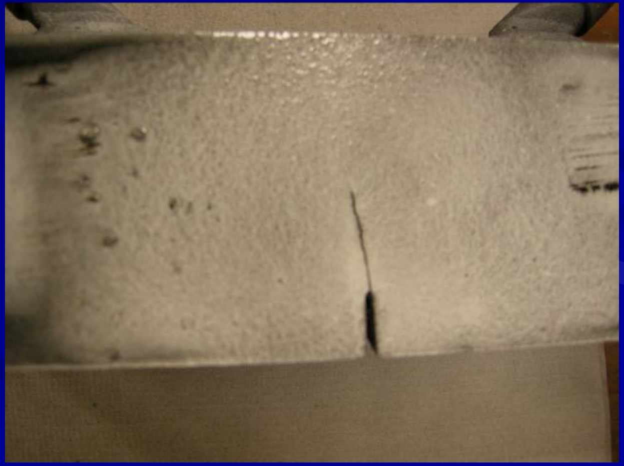
Experiment

- On completion of the experiment, the crack can be seen at the edge of the specimen
  - The top image was taken while still at ~600°C
  - The bottom image shows the result of a magnetic particle inspection
- The crack growth visible at the edge of the specimen is approximately 20mm. This compares reasonably well with the growth estimated from the UT measurement which is 16mm±1mm.



Discussion

- The trials performed have clearly demonstrated the feasibility of measuring fatigue crack growth at high temperature in steel components.
  - The high temperature probes, probe attachment method and the measurement technique have all been verified at 615°C.
- The next stage in the on-going programme will be a trial installation on a known crack in an operating plant. This is currently planned to take place this summer.

Discussion

- Work is continuing on the instrumentation in preparation for the planned trial. The main areas being addressed are:
  - Remote operation
    - It is clearly desirable that data collection and analysis should be able to be controlled from a remote location, and we are working on a solution using GPRS data transmission.
  - Minimizing the influence of temperature variation
    - In the experiment reported, temperature was held constant and velocity change was not a problem. However, in a plant application, where temperature changes are driving the crack growth that is being monitored, there will be large velocity variations.
    - To reduce the influence of temperature on UT measurements, the instrumentation and software are being modified to allow data to be collected when the component temperature passes through a temperature set-point.