Innovations in Inspection and Monitoring Techniques for High Temperature Plant

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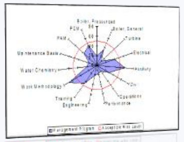
- Engineering & R&D company based in Surrey, UK
- Power & Process Plant Inspection & Condition/ Life Assessment

Specialist Institutions → Research → etd ← Knowledge ← International Experts

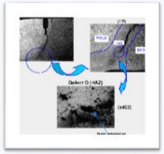
Application

Conventional Steam plant, CCGT, HRSG, Petrochemical, Refining + other industrial sectors

- Collaborative R&D / Technology Development
- Plant Integrity
- Plant Services
- Training & Technology Transfer

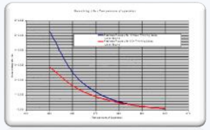


RBI, RBM, FFS

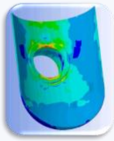


Weld Repair Expertise

- Life Assessment
- Welding & Repairs
- Heat Treatment
- Int. P91 User Group



Crack Assessment (RLA, FFS)



Stress Analysis – CAESAR Pipeline Stress Analysis / FEA

ETD's Products / Software

A compendium of lifing procedures
- for power plants / HRSGs

e-Atlas - database of ageing microstructures with 11,000 replicas

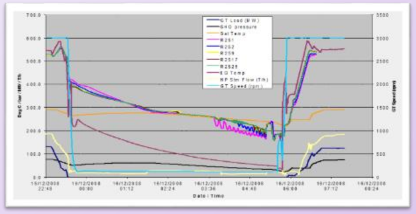
CRACKFIT Crack Assessment Procedure & Software

MAS Maintenance Advisory Software

- Boiler Lifing Procedure
- HRSG Inspection, Monitoring, Repair & Lifing Procedure
- Boiler tube Failure Management Guidelines
- Procedures for PP/ CCGT Preservation during shut down

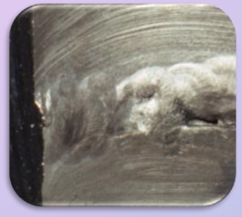
Cyclic HRSG/CCGT
Assessing plant cyclic capability:

- Materials Design & Performance
- Start up/shut down – technical parameters & costs
- Condensate calculations
- Allowable no. of cycles
- Damage mechanisms
- Life assessment
- Cost modelling



Effects of cyclic operation on both conventional power plants and CCGT's- with regard to damage, technical and cost issues

Technical & Cost Analysis for Component Replacement in Ageing Plant



Performance / integrity of weld repaired components in ex-service conditions

Development of Innovative Inspection and Monitoring Techniques

- **EDSE** – portable ‘spark erosion machine for ‘boat sampling’.
- **SFM** – portable Atomic Force Microscope for on-site early-stage damage detection.

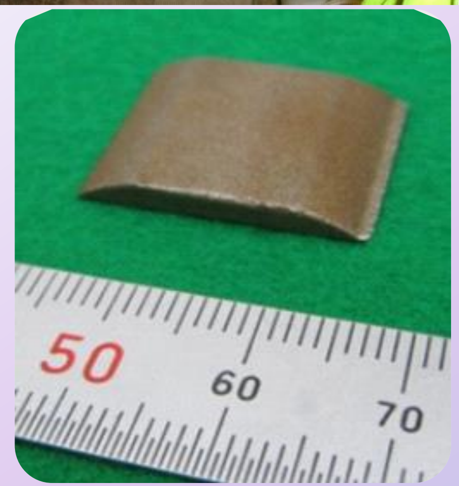
- **Smart Sleeve** – for more accurate on-site hardness testing.
- **LSG** - Laser Strain Gauge
- **Magscan** – to fast scan P91 and P92 components for ‘aberrant’ microstructure.
- **LFET – BFET** – fast scanning of boiler tubes for wall thickness loss and cracking damage detection.
- **PD** – AC+DC Potential Drop equipment for creep cavitation damage monitoring.

EDSE (Electrical Discharge Sampling Equipment) - *for 'boat sampling'*

Quantitative life assessment and miniature specimen testing for RLA

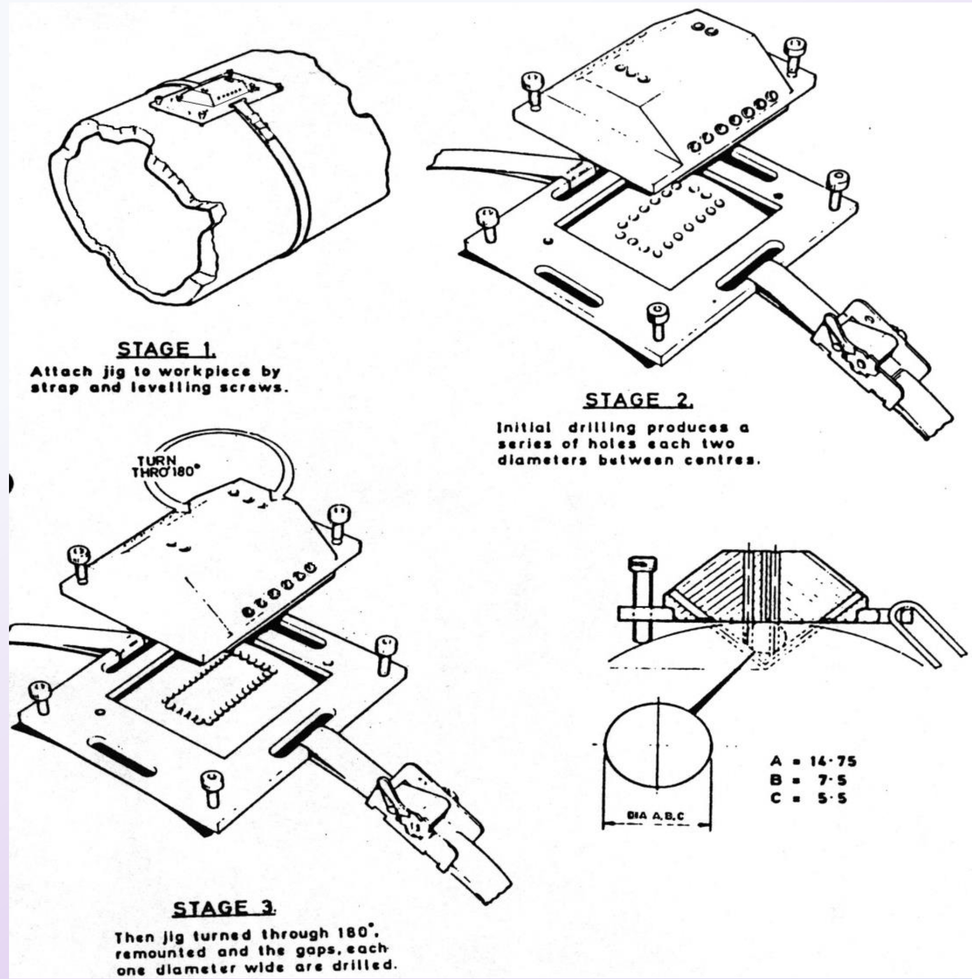
Needs cutting out small slices (almost non-destructively) for testing.

From top left (clockwise): EDSE cutting a sample from the reducer pipe; 4mm thick piece cut out from the pipe; round edge cavity left behind

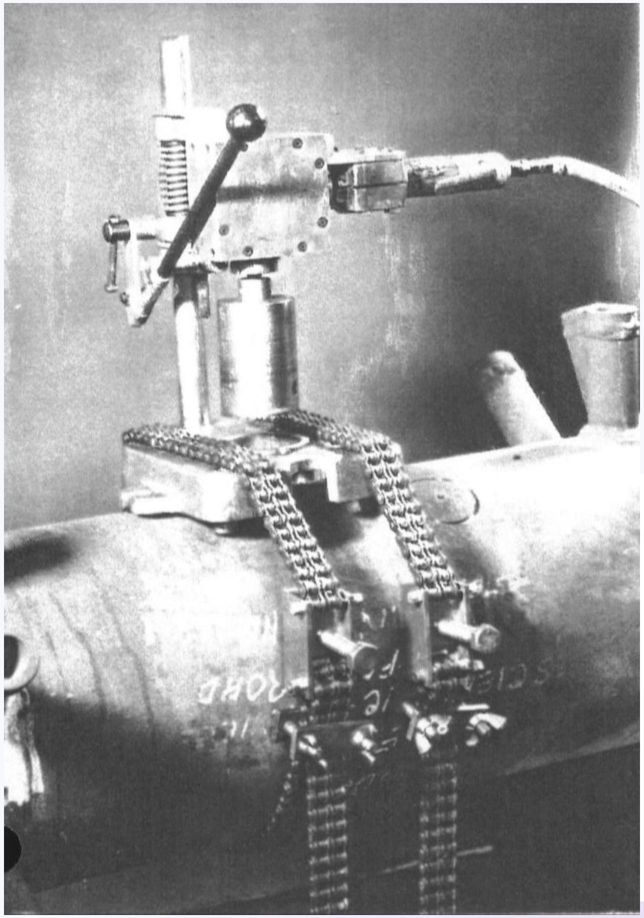


Chain Drilling – *old traditional method*

- Jig allows positioning of drilled holes
  - Provides sufficient material for testing
  - May require weld and PWHT or blending



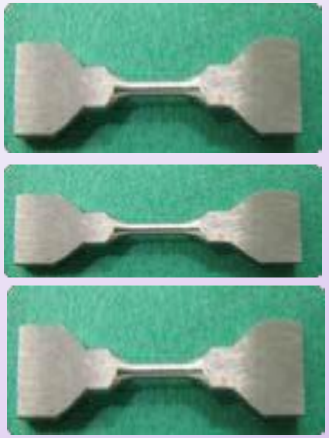
Plug Trepanning - *old traditional method*



- Supplies a through-wall sample
  - Typically used for metallurgical investigation
  - Miniature samples can be extracted
  - Repair by welding blind stub over hole
  - Not taken from worst position
  - Mark up directions before cutting

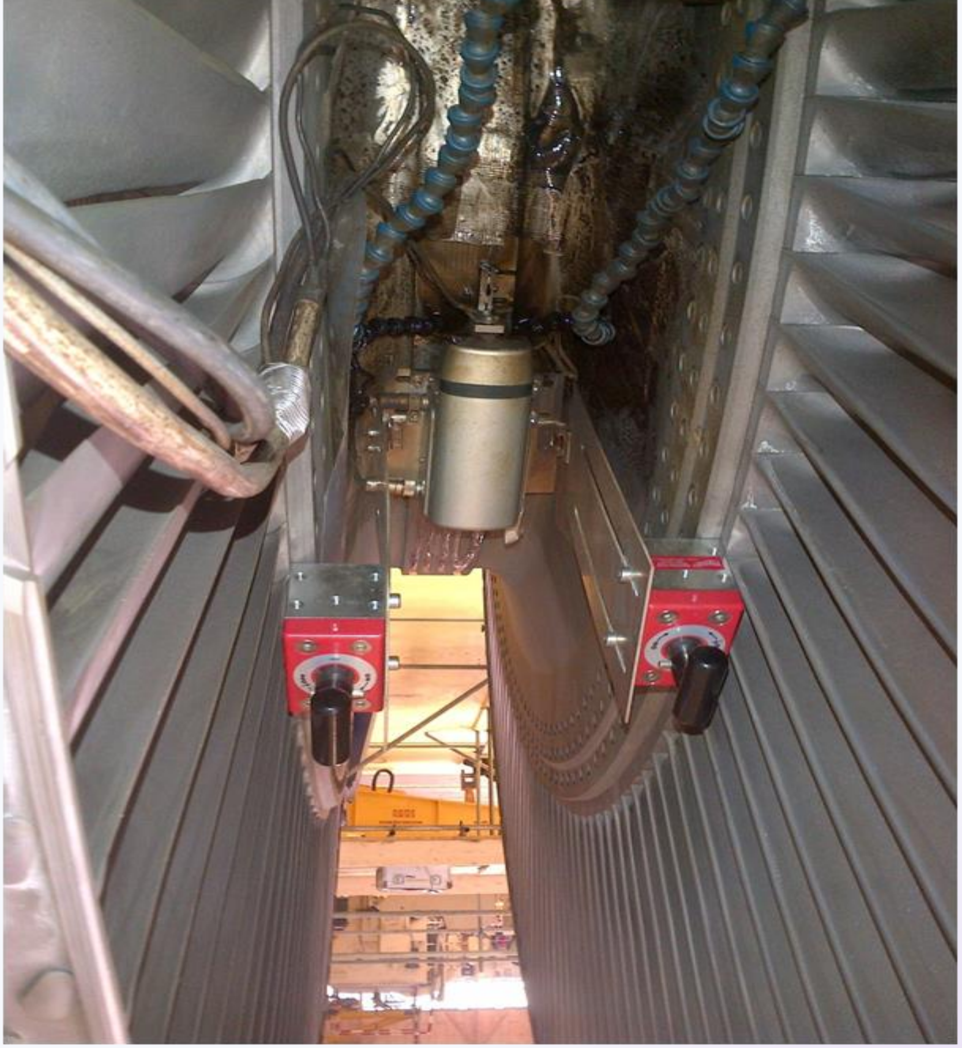

KMT


50
60
70



Sample Sizes

- **Thickness** = 1 to ~20 mm
- **Width** = 20 to 40 mm
- **Length** = 25 to 130 mm

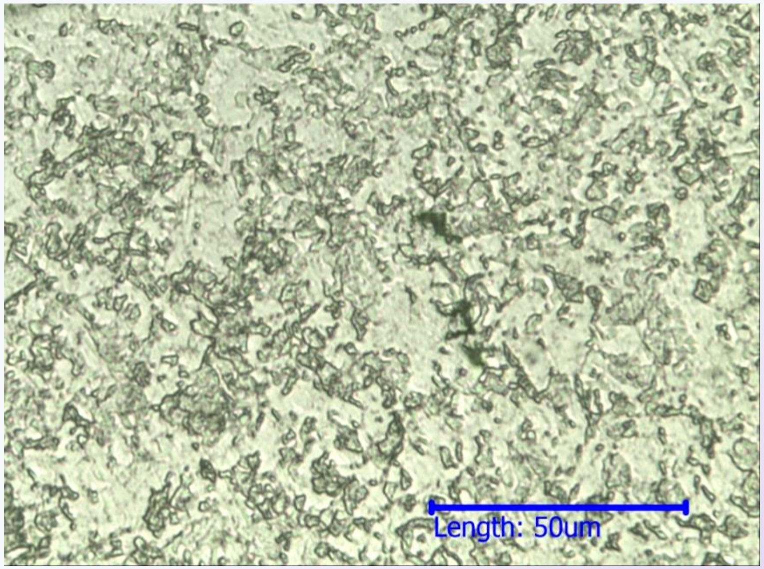


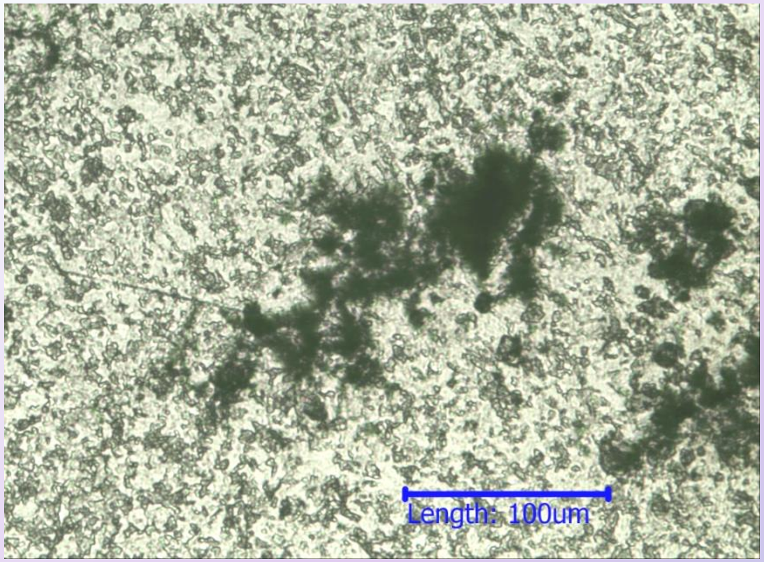
EDSE mounted between 2 discs of a rotor using magnetic mounts (red tops).

Sample cut from a rotor between two discs.

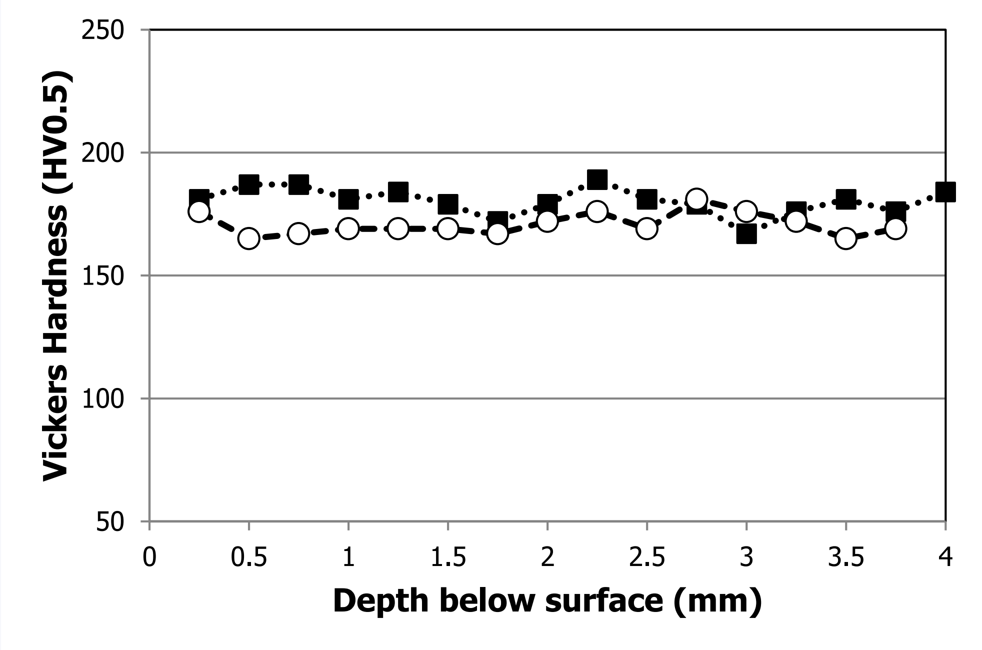
Photomicrographs showing examples of creep damage at over 70% of life

LHS: Damage in fine-grained HAZ adjacent to outer surface.
RHS: Damage in fine-grained HAZ some distance below the surface.





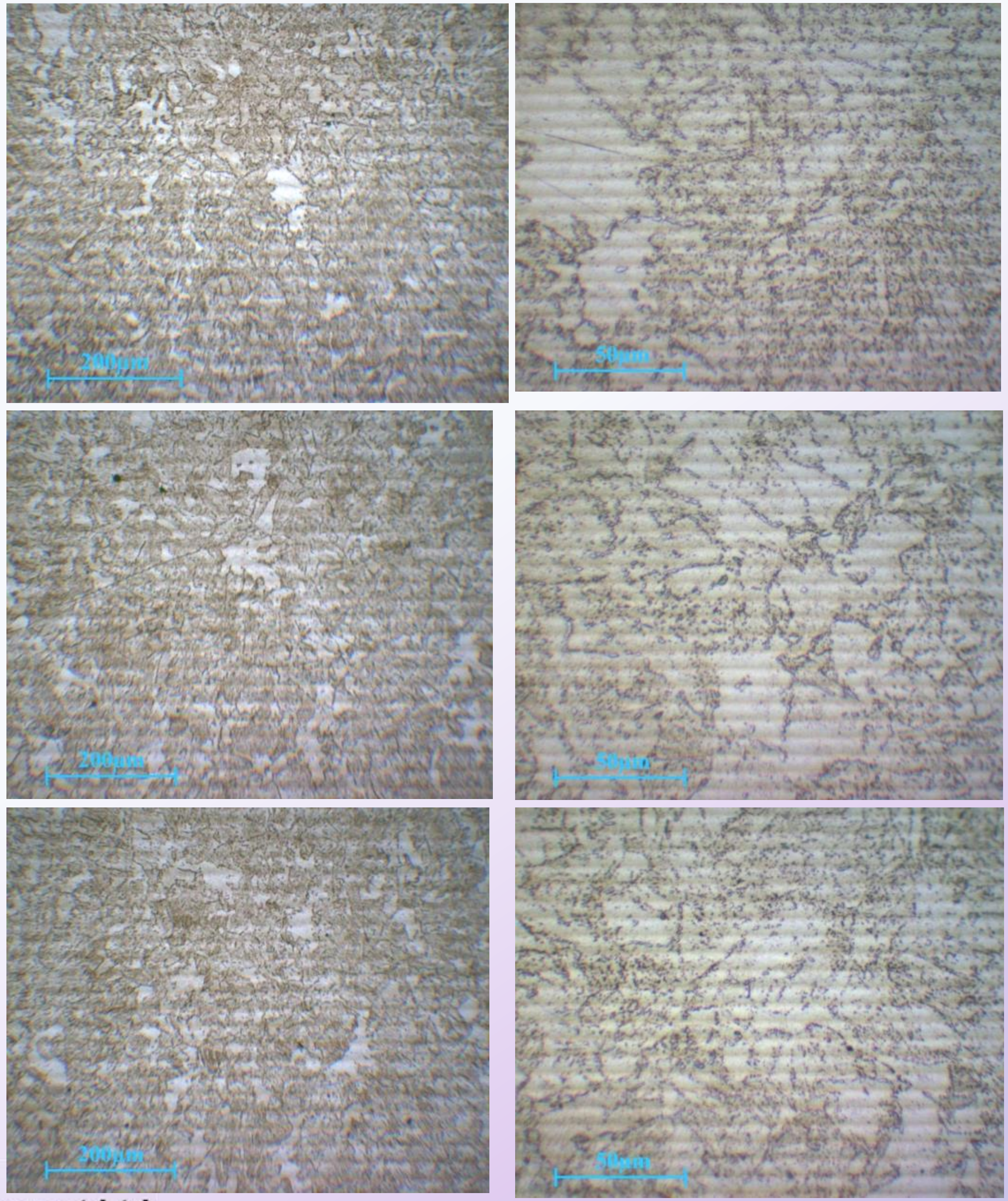
Quality Check

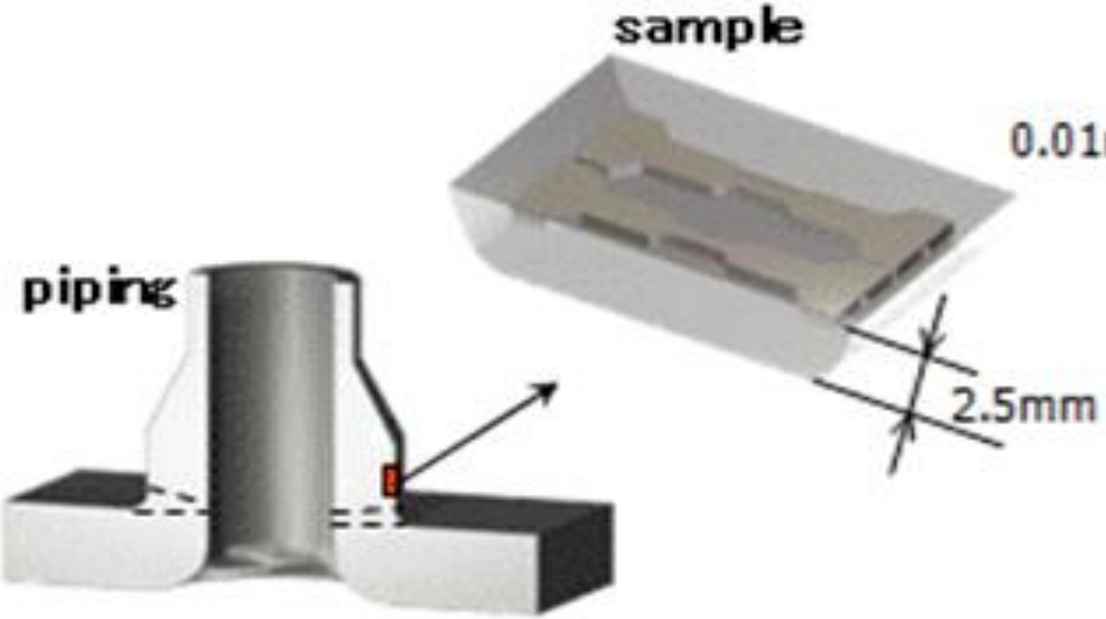


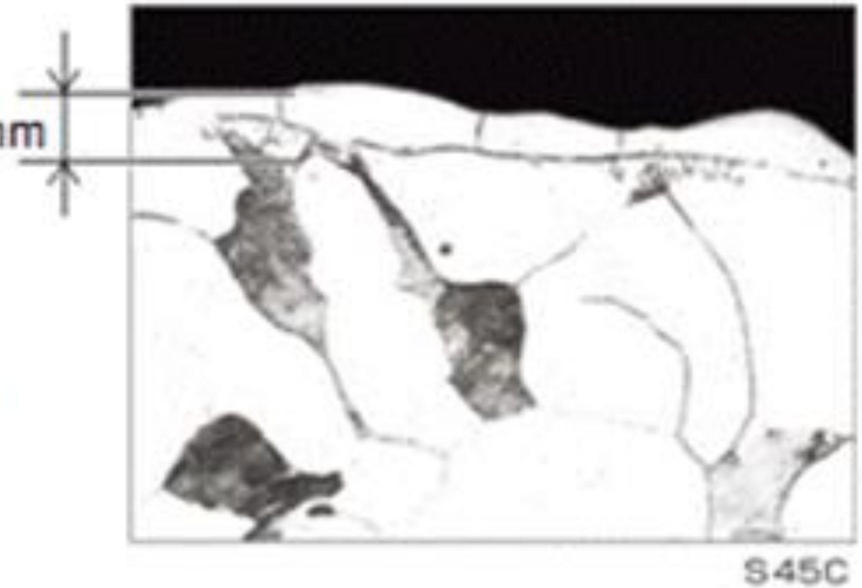
Micro-hardness traverses of EDSE ‘boat’ samples

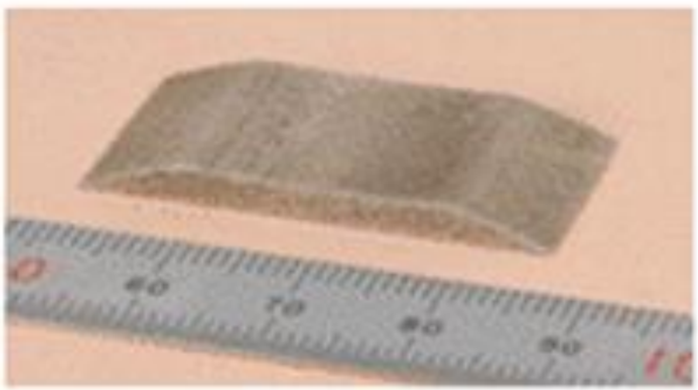
- **Microstructure of P91 did not change significantly from surface to 4mm depth**
- **No increase in hardness below surface**
- **Thus, the results confirmed an abnormal microstructural condition with poor mechanical property levels.**

Top photos: Close to the component surface (i.e. approx. 0-1mm depth)
Middle photos: Middle of thickness of EDSE sample (i.e. approx. 1-3mm depth)
Bottom photos: Close to cut-surface of EDSE sample (i.e. approx. 4mm depth)

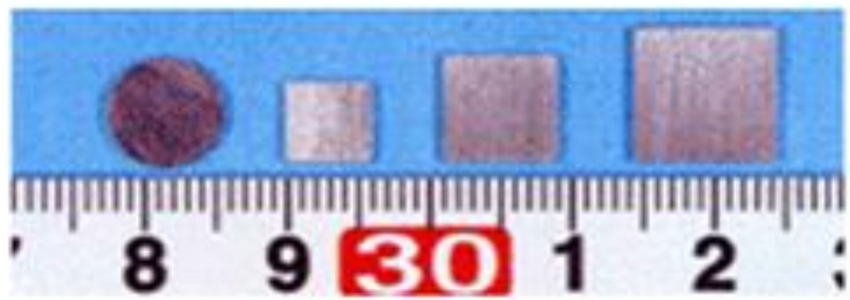






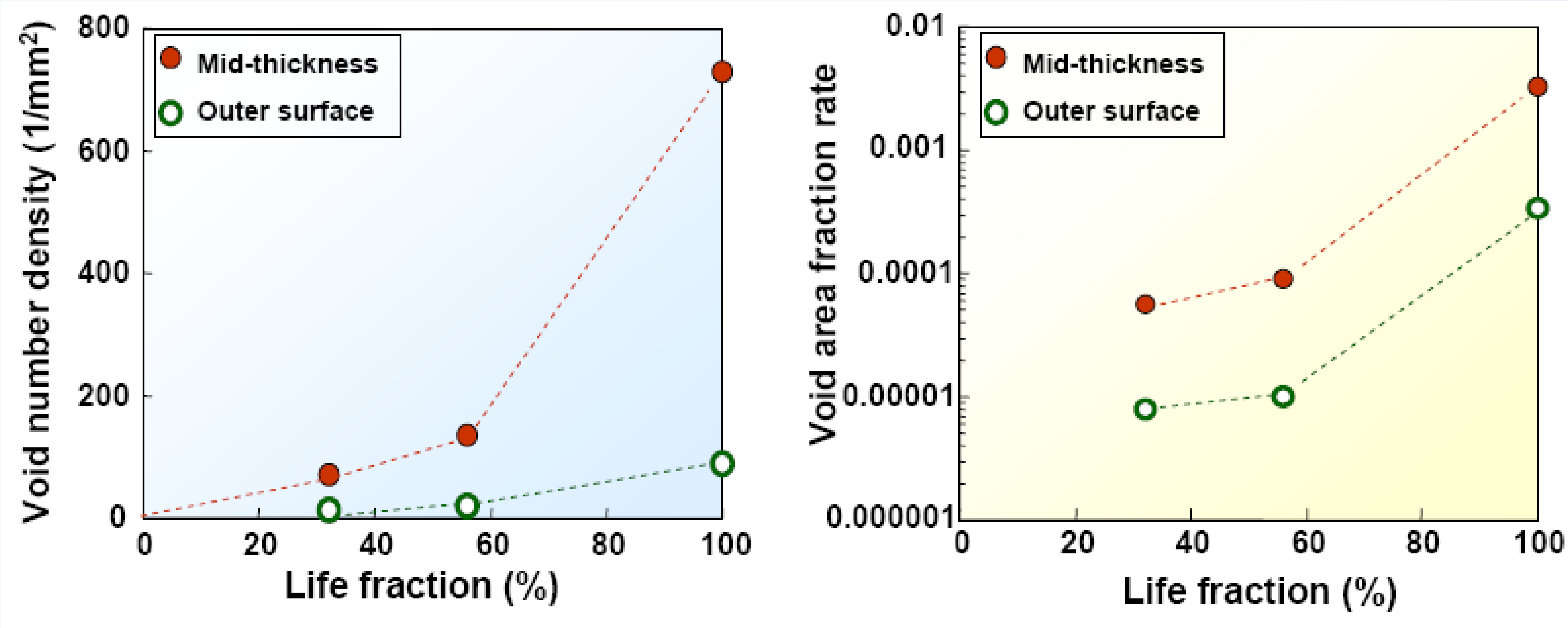


Specimen geometry after sampling

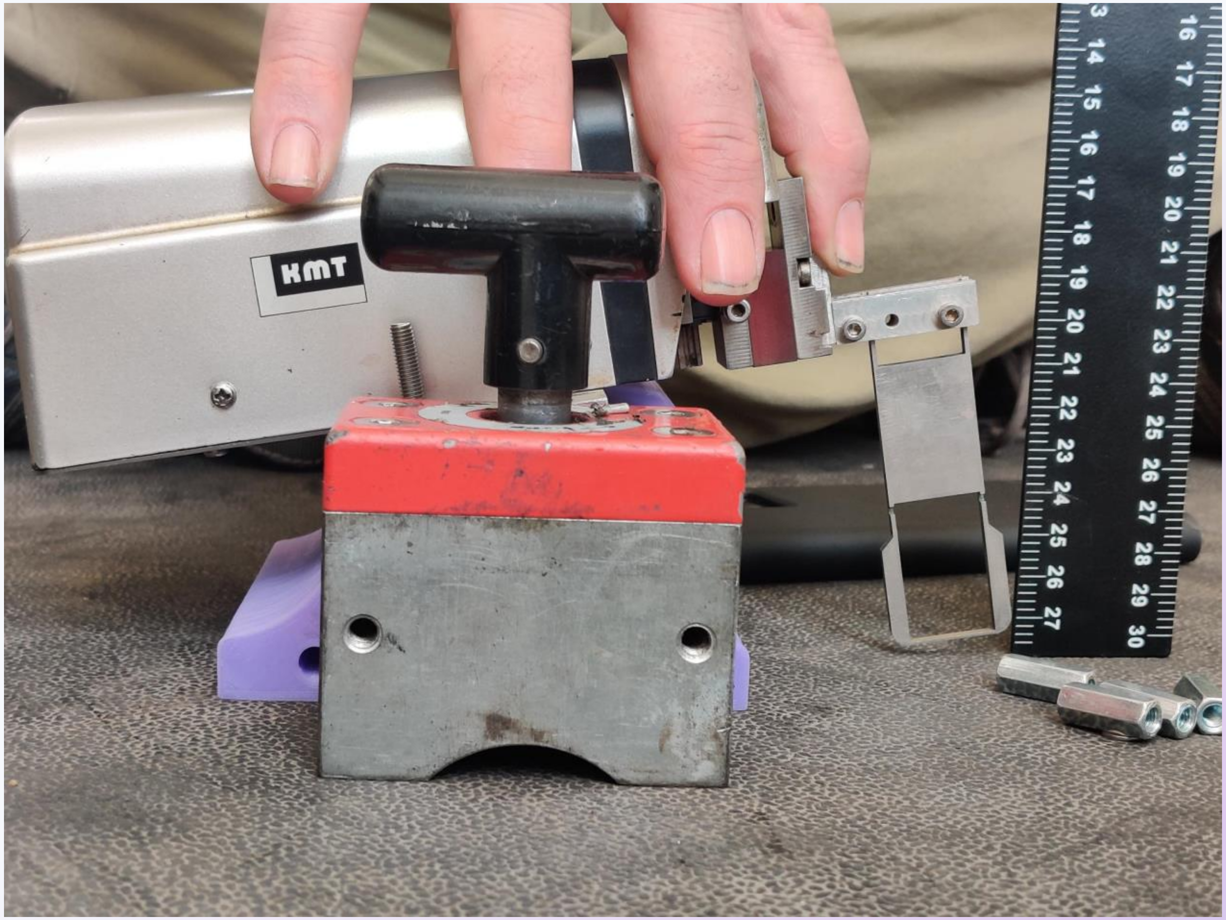


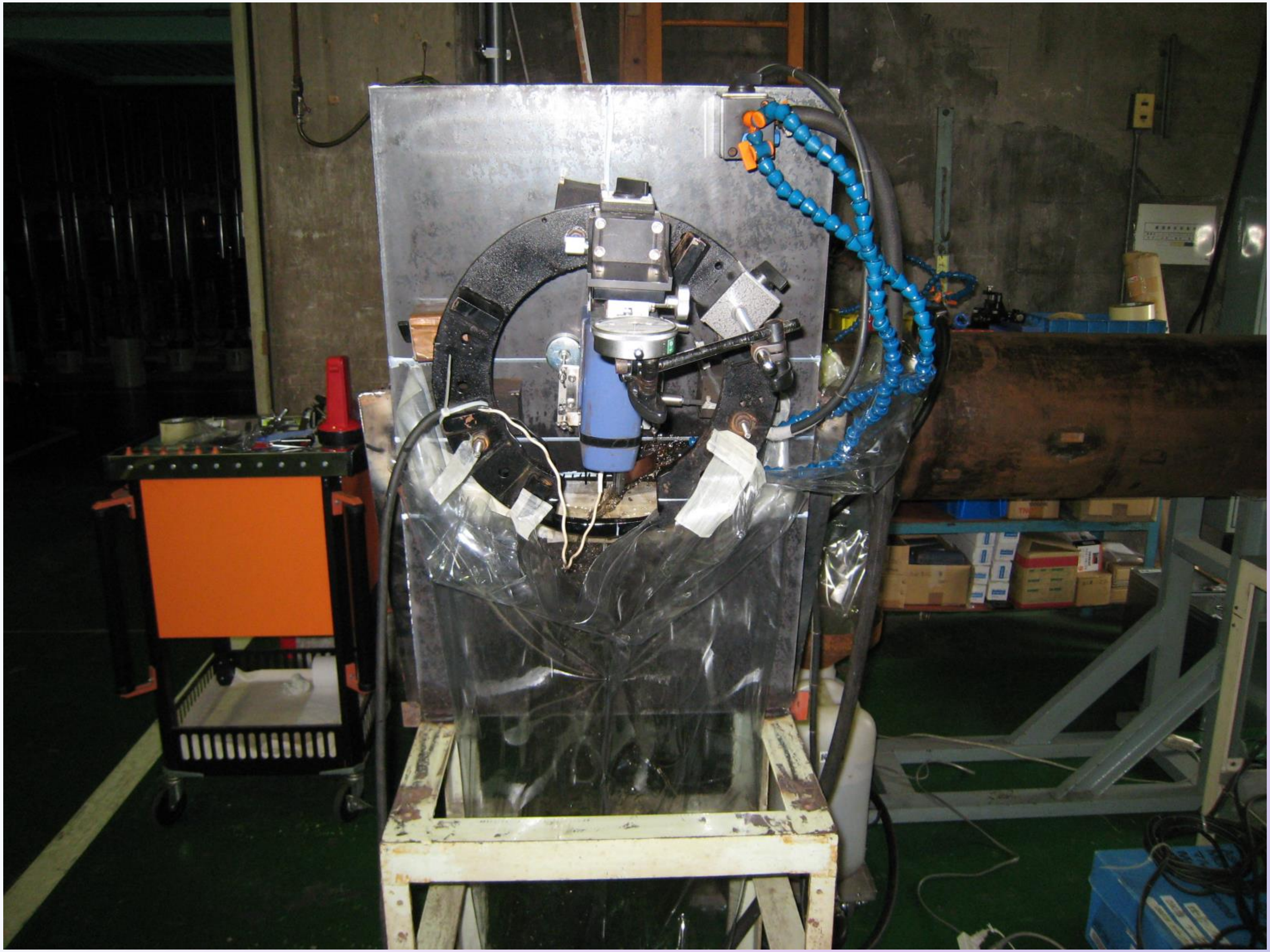
Specimen after sampling

Creep damage development in welds



Ref: Ogata T, Sakai T, Yaguchi M, "Recent study on creep damage assessment methods of P91 weld joint in CRIEPI", Proc. Int. Seminar 'Use of 9-12Cr Martensitic (P91, P92, P911, P122) & 2Cr Bainitic (P23, P24) Steels in Thick and Thin Section Components', 10-11 Sep 2008, London, UK


KMT



Development of Ultra Miniature Creep (UMC) Specimen Testing

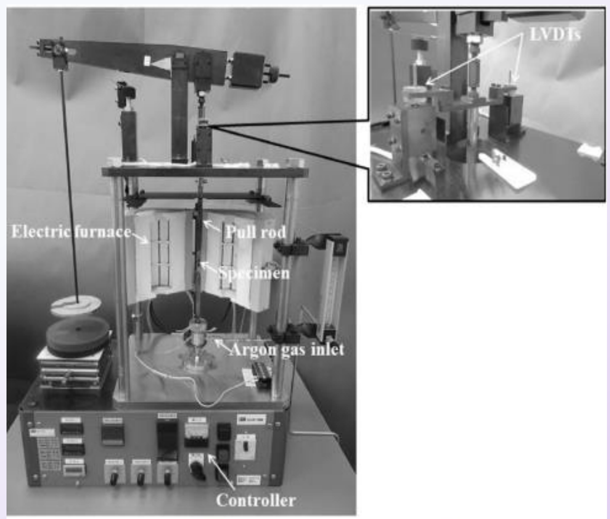
UMC specimen testing from 1 mm thin boat samples has now been developed in Japan. **This technique is now being offered by ETD outside Japan** through a newly consortium established between ETD and its partners. Useful for very critical components where loss of wall thickness cannot be afforded**.**

Miniature creep test specimen

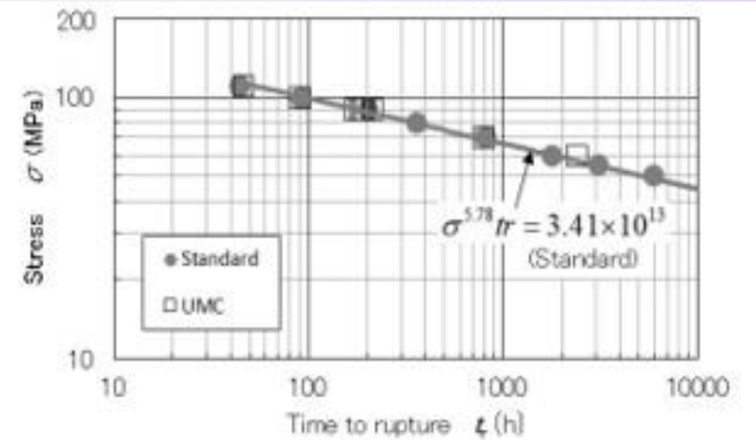
Small punch creep test specimen

Ultra-miniature creep test specimen

Comparison of appearance between typical specimens



Testing equipment



Comparison of Ultra-miniature creep (UMC) test results with standard specimen data

Material: Grade 91 steel
(Long-term used)

Temperature: 650°C
Stress: between
110 and 60 MPa

Maximum rupture time:
about 2400 h

Conclusions

EDSE sampling equipment can be used for:

- Quality checks on new materials.
- Damage assessment of in-service thick section components non-destructively.
- Quantitative life assessment for more accurate and reliable plant service.
- Assessment of cracks in turbines and rotors without destroying them.
- Assessment of damage inside pressure vessels.
- Can be used for damaged weld excavation and repairs.

Scanning Force Microscope (SFM)

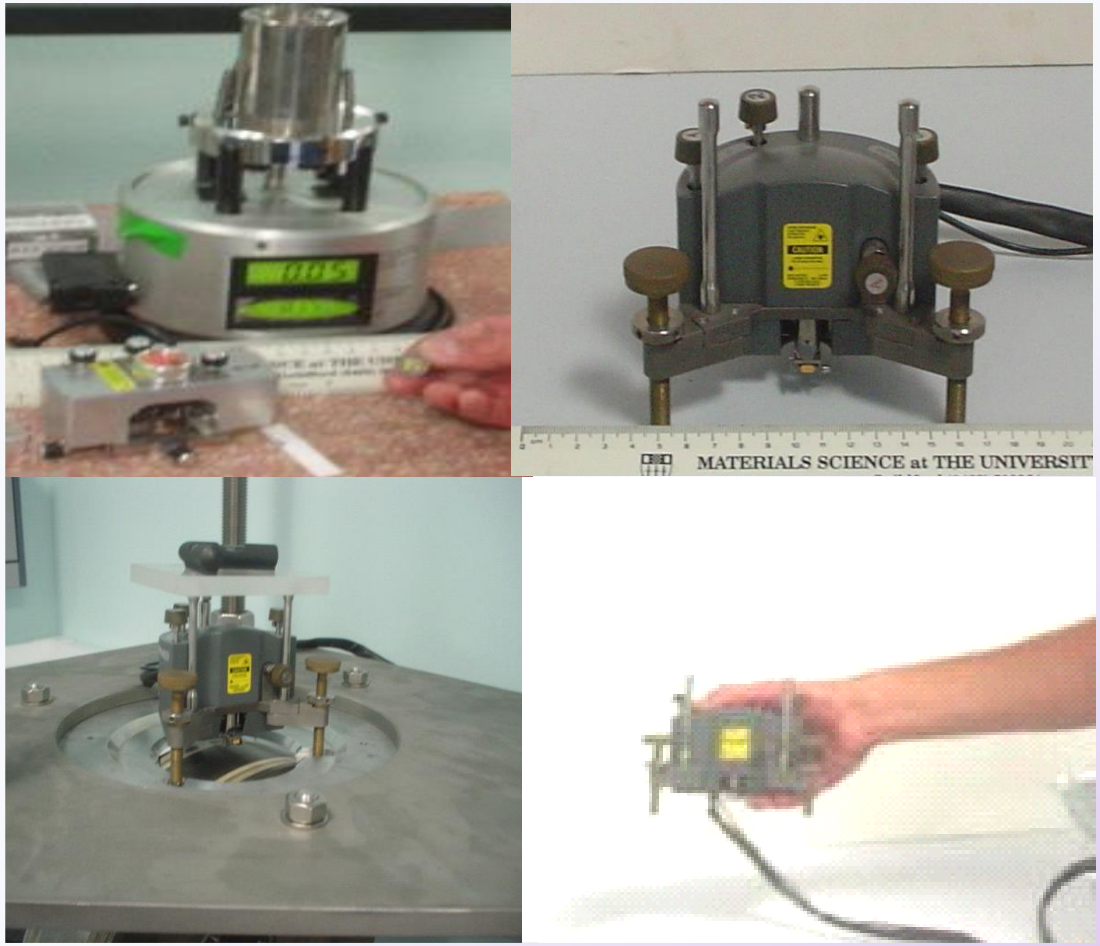
for

On-Site Early-Stage Damage/ Creep Cavity Inspection

BACKGROUND of Development

Problems with the inspection & integrity/ life assessment of some of the modern steels (ASME P91) for the new generation of power plants

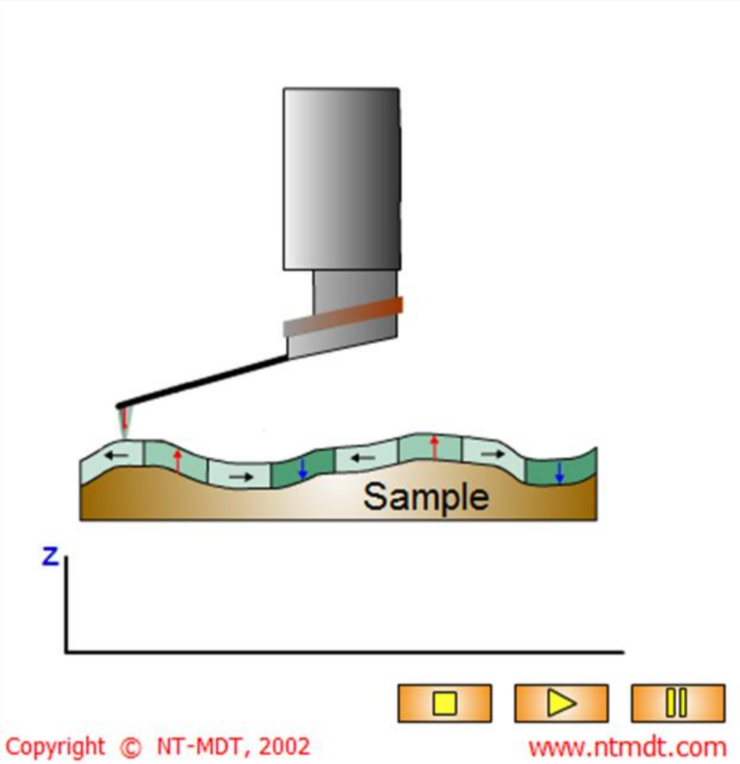
- Creep cavitation by replication does not show until late in life (~80% life).
- Traditional UT methods do not detect nano level damage until about 70% of life.

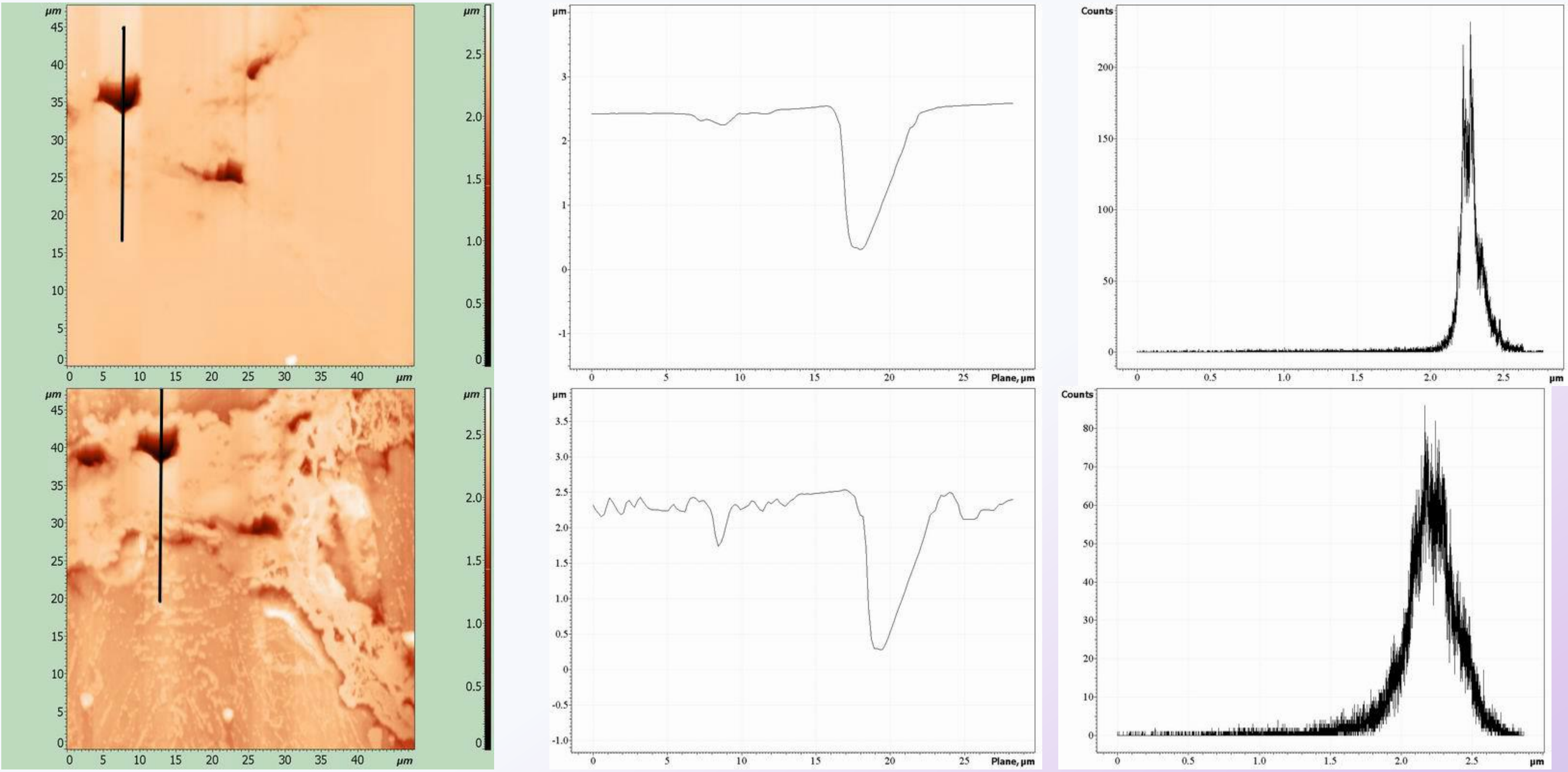


Atomic or Scanning Force Microscope. From top left hand (clockwise)- Lab version, portable version, portable version hand held, portable version in use on a pipe ring

Scanning Force Microscope [1/4]

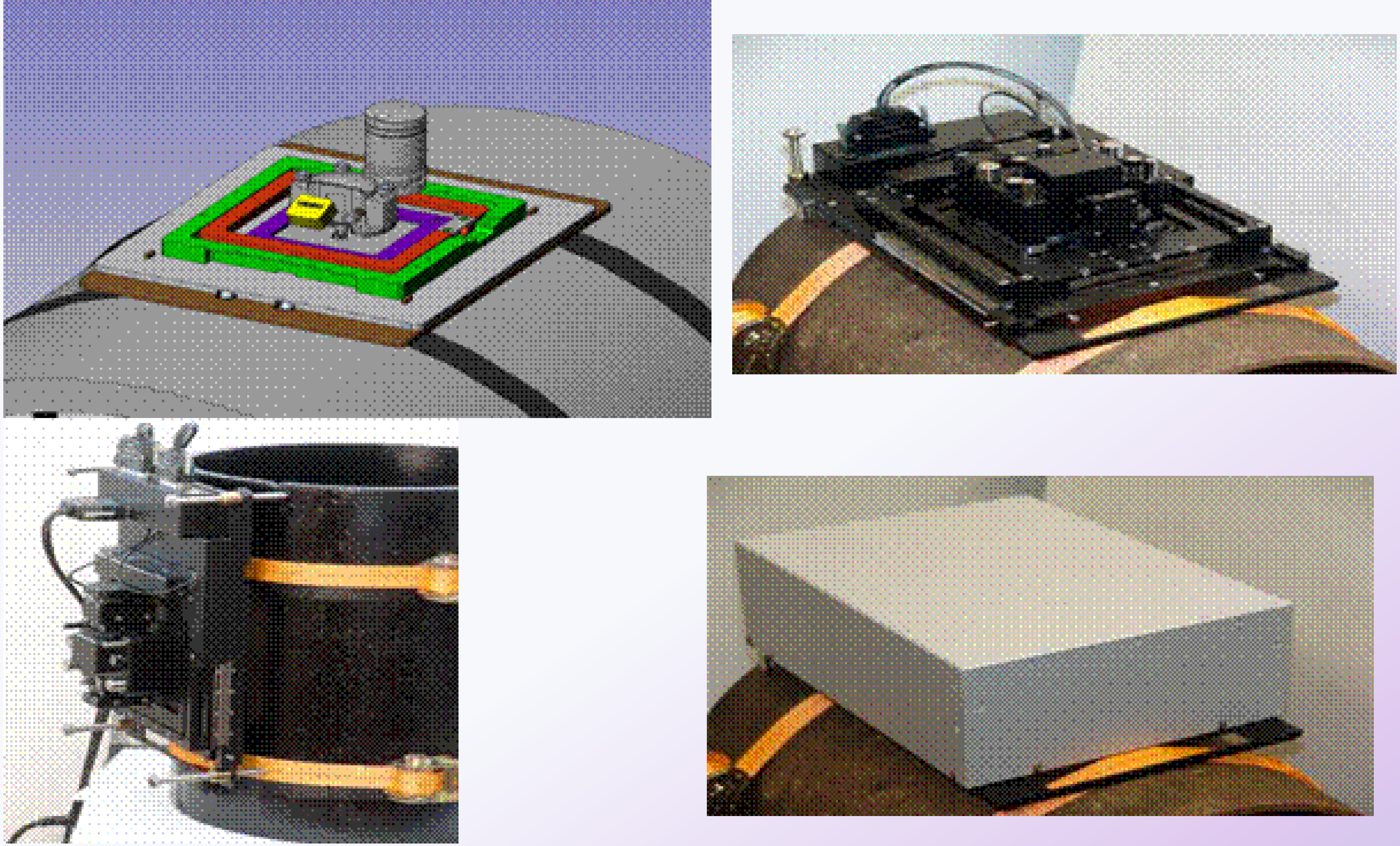
Portable atomic force microscope:



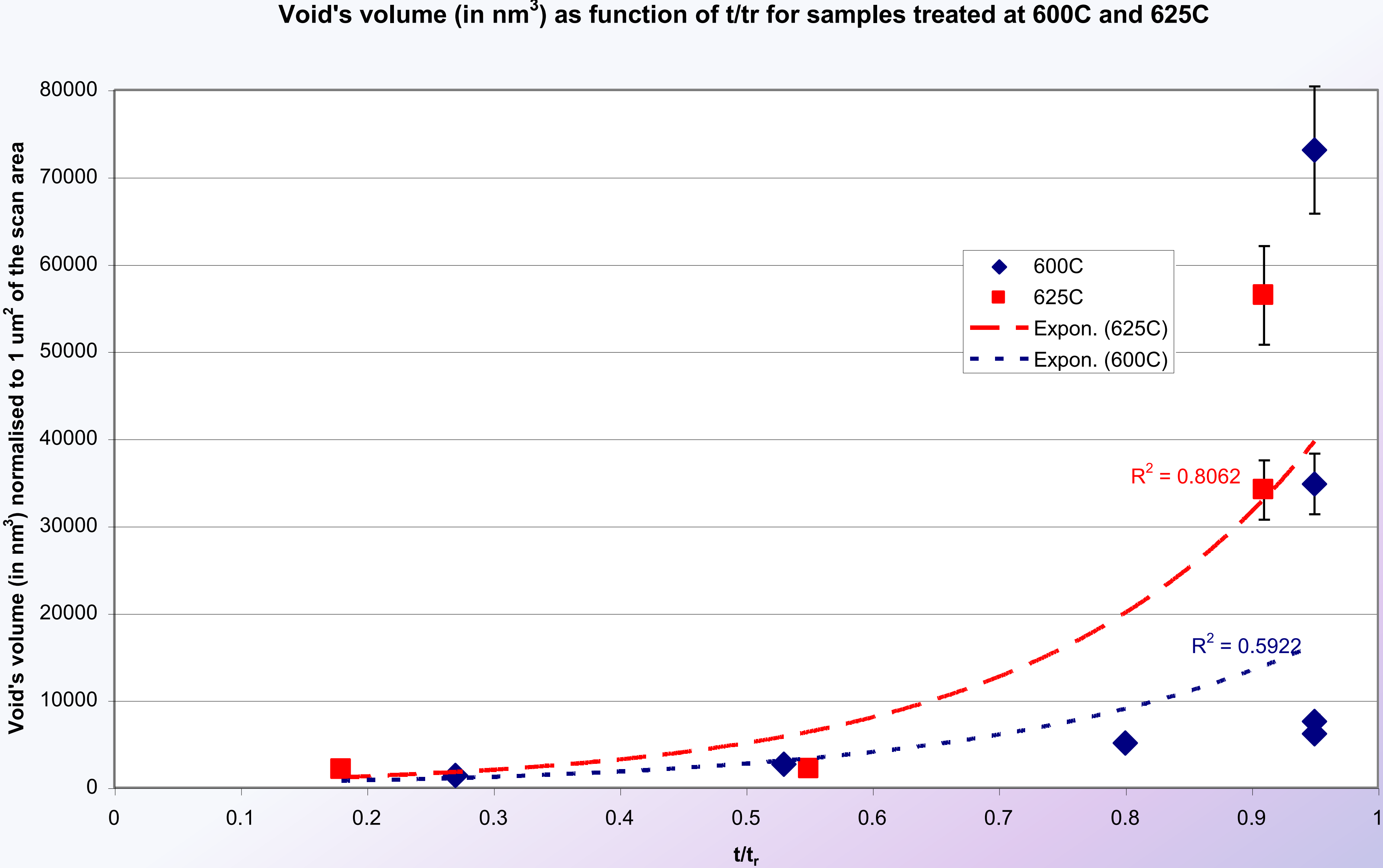


SFM images acquired before and after chemical etching.

Height data and depth distribution curves are shown at RHS



New SFM with the mounting frame. Clockwise from top left: Schematic with the mounting frame, SFM mounted on a horizontal pipe, SFM enclosed in a box for safe keeping in plant during use, SFM mounted on a vertical pipe

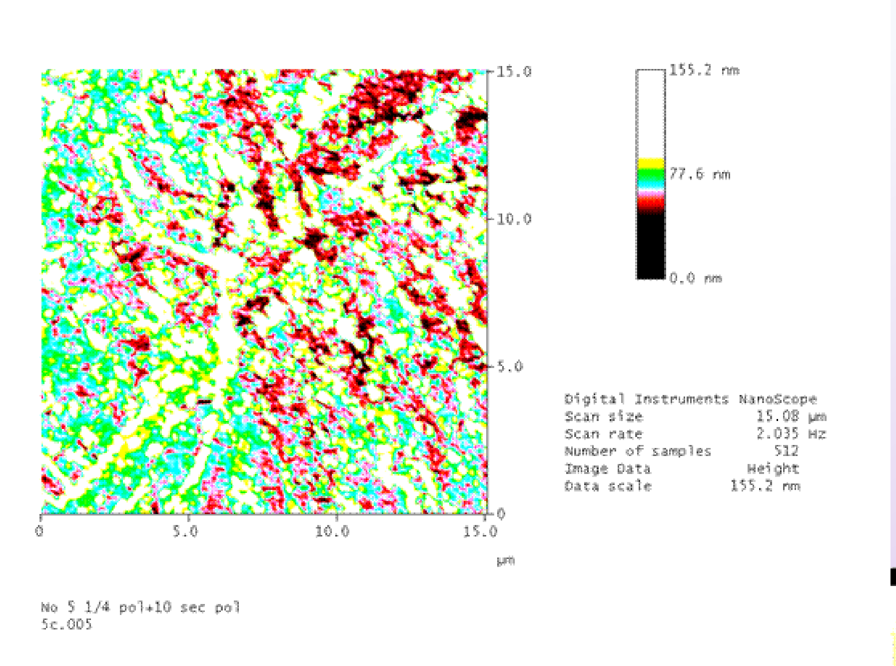


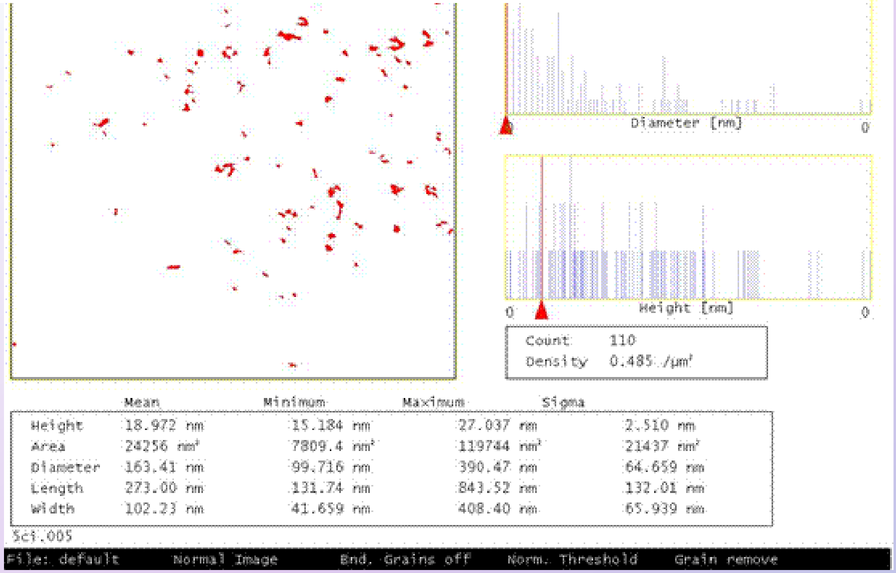
Cavity volume plot for the specimens tested at 600ºC and 625ºC

Creep specimen tested at 625C and interrupted at 18% of life

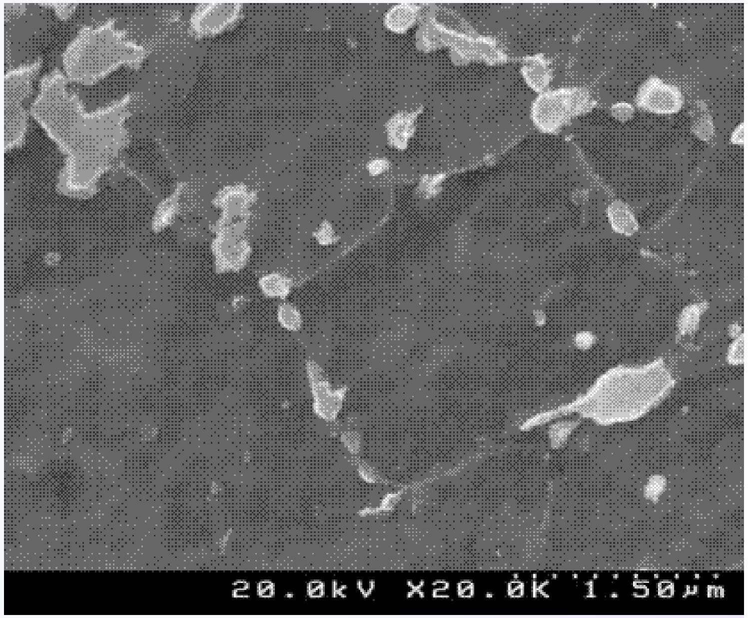
Top: SFM cavity micrograph (black spots are the deep cavities)

Bottom: Footprint of the cavities

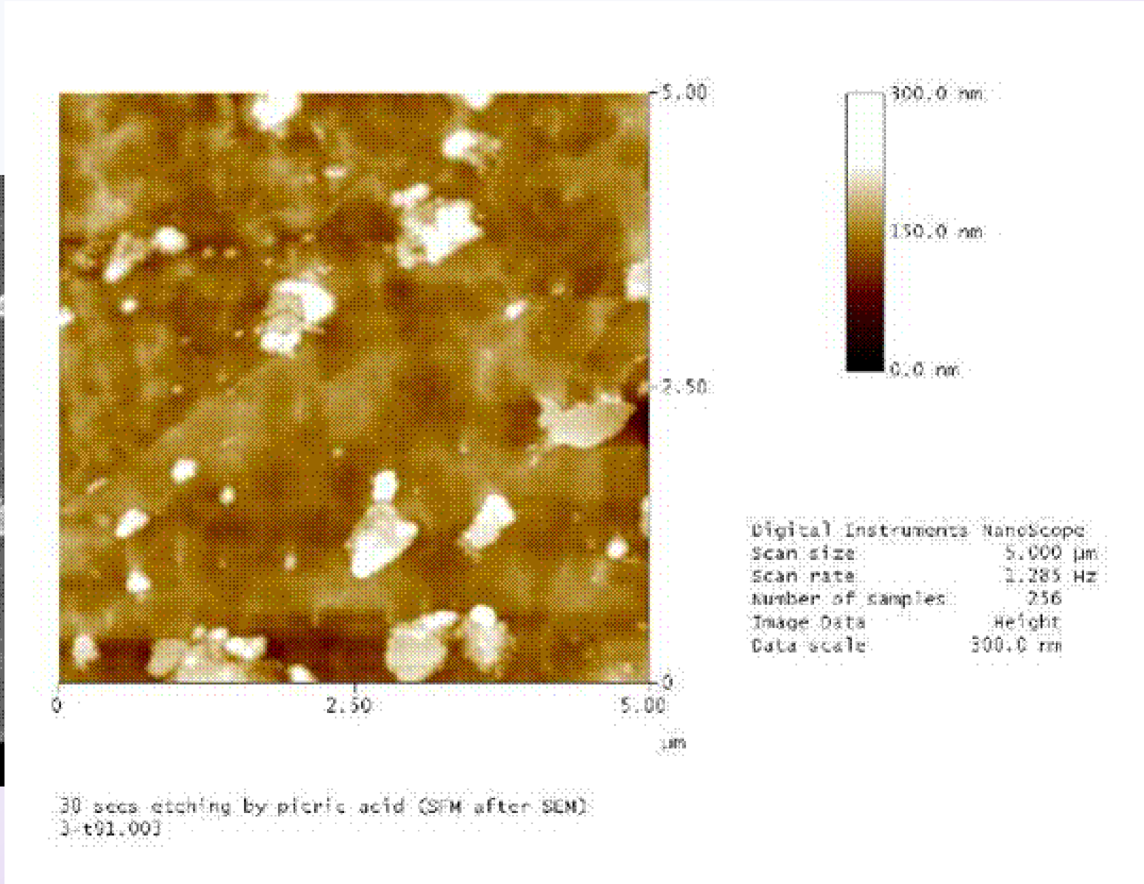


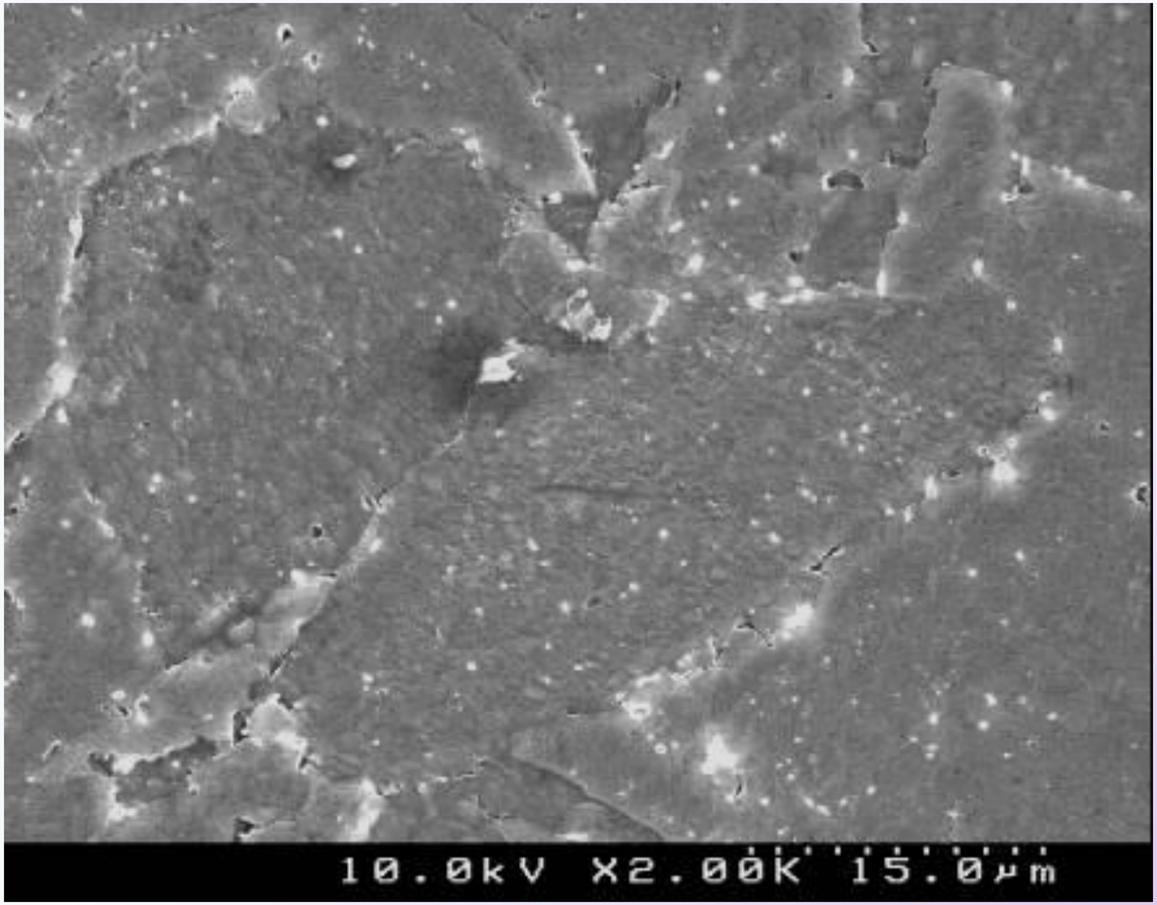


P91 after Etching - SEM versus SFM

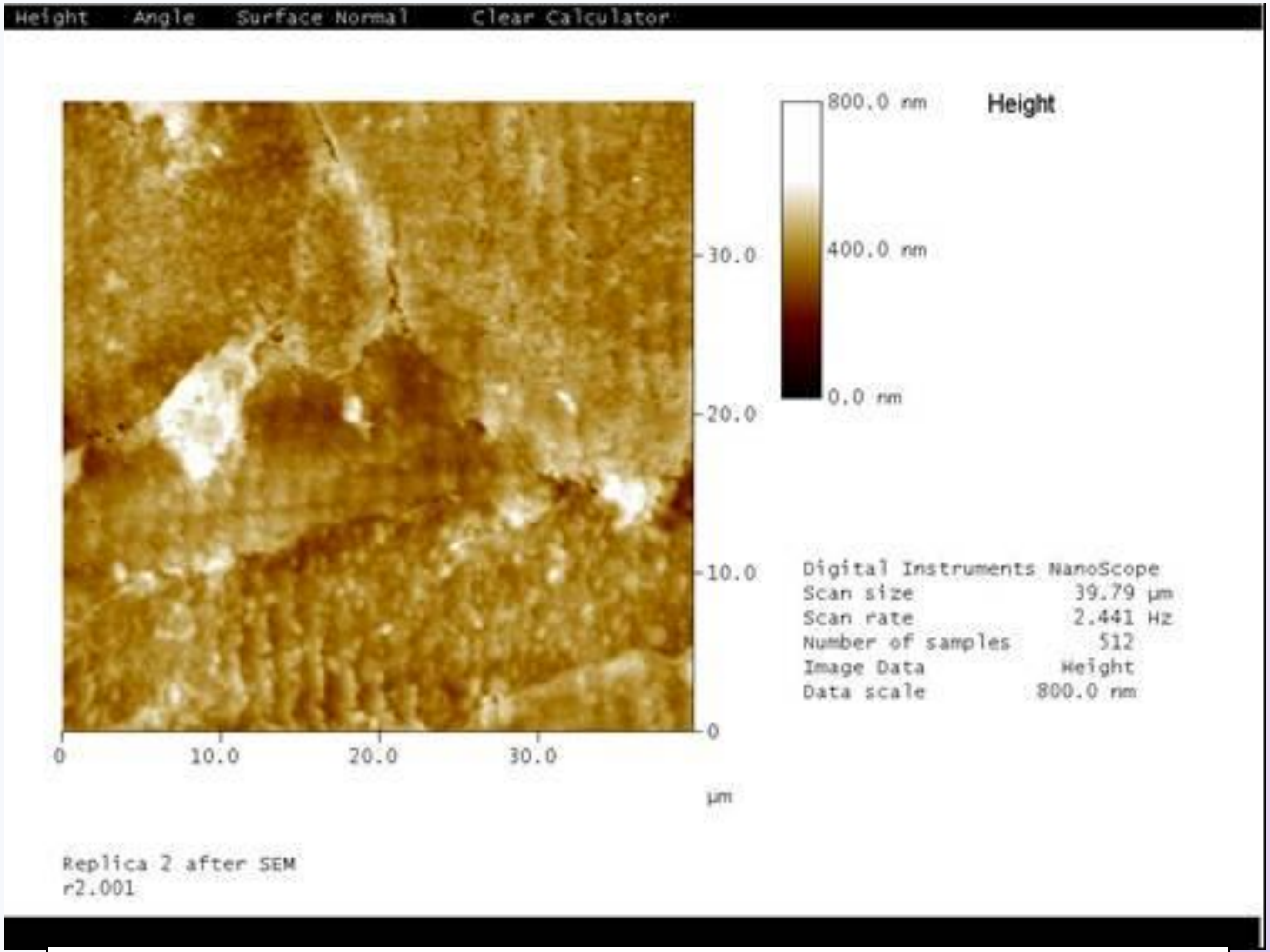


SEM

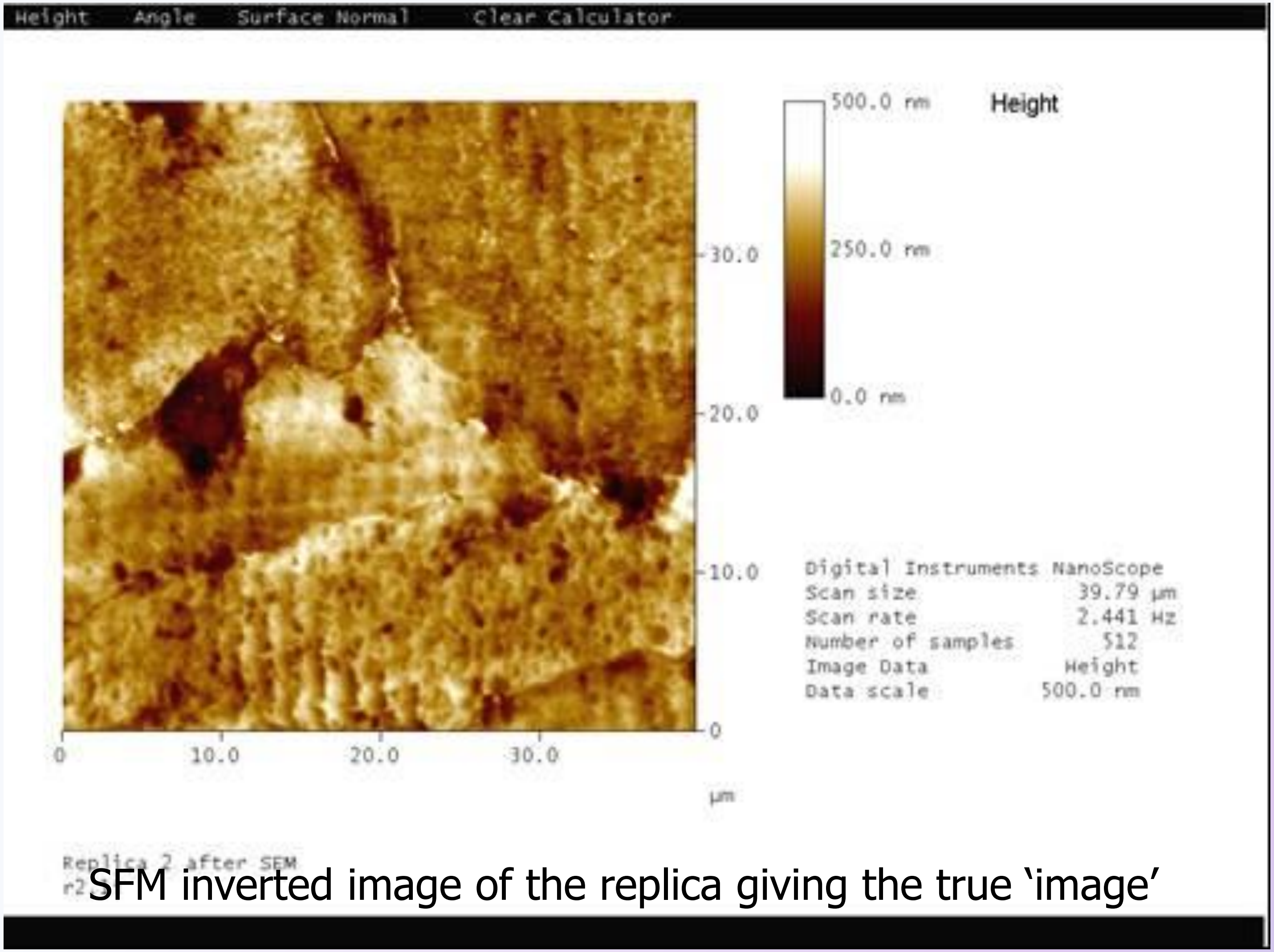




SEM image of the replica of a creep damaged specimen



Replica image using SFM



SFM inverted image of the replica giving the true 'image'

Raffineria di Roma, Rome Italy, 18-19 May 2010

Dr Ahmed Shibli (ETD, UK)
Jorge Fernandes (ETD, UK)

Dr Peter Zhdan
(Consultant, UK)

Dr. Andrea Tonti (ISPESL, Italy)

Kirill Balizh
(NT-MDT, Russia)


Examination position polished to 1 micron level (same as for replicas)

SFM use on Pipe 1

Mounting Versatility

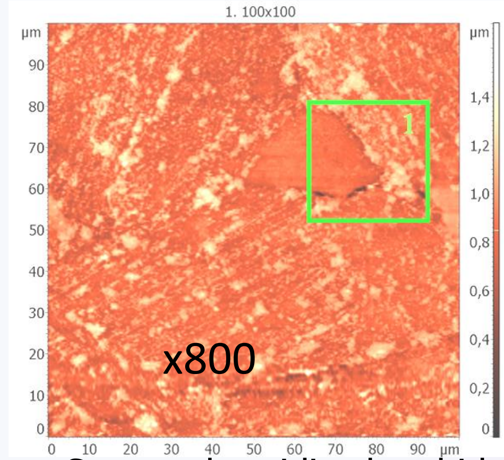
1st Stage of Rotor

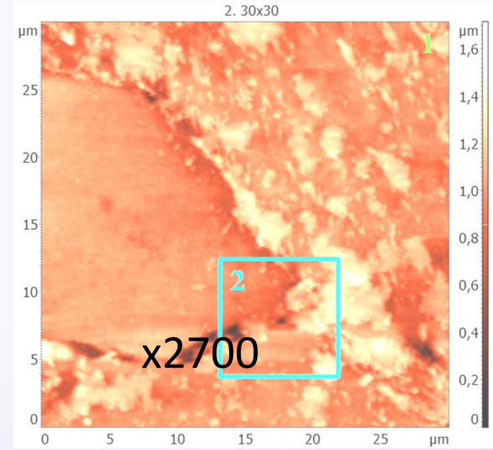
2nd Stage of Rotor

Rotor Hot Section End

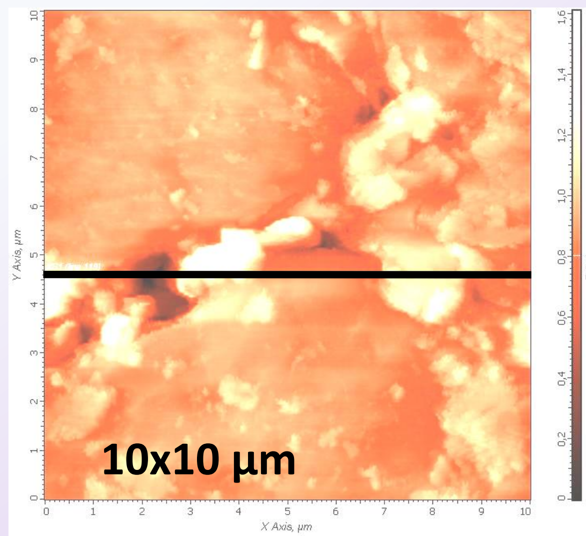
Rotor 1, location 4

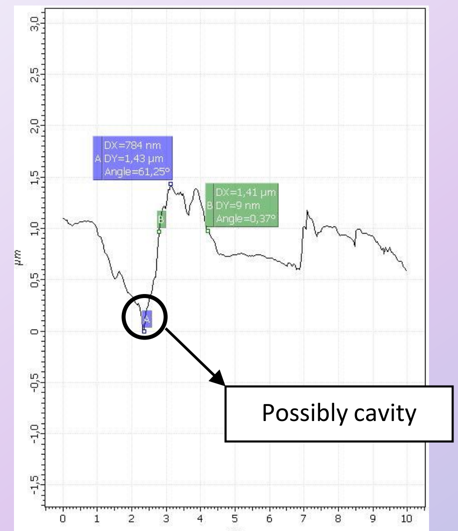
SFM findings





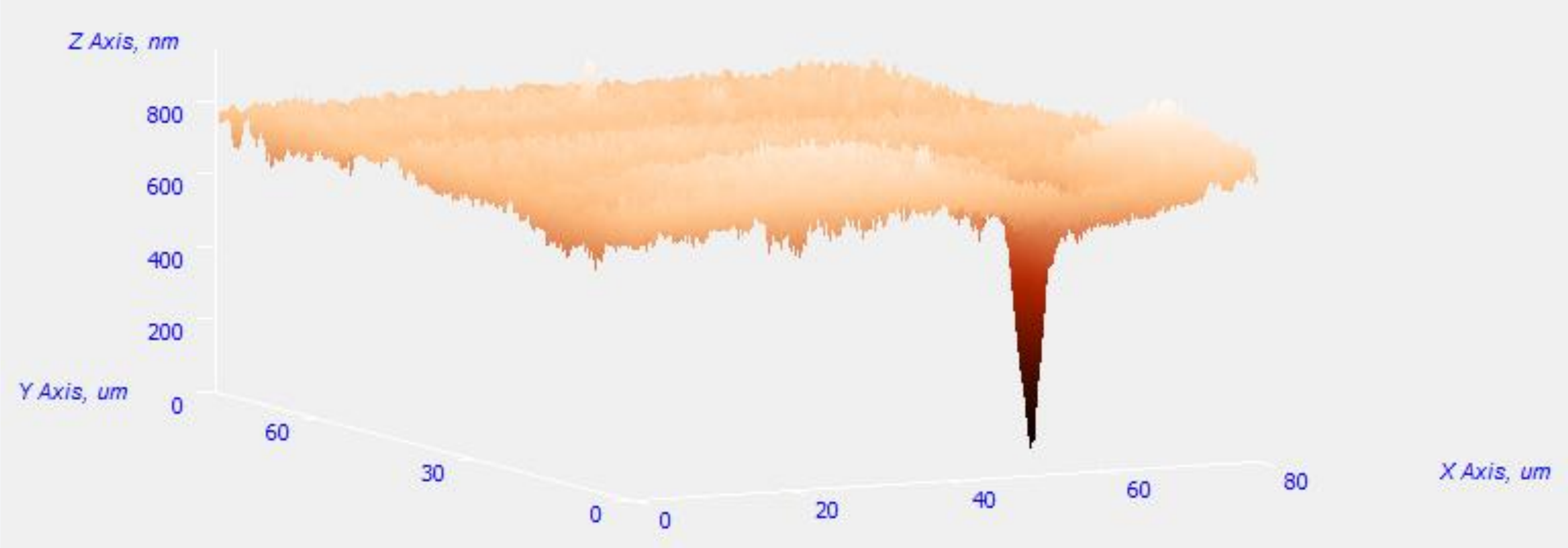
Some spheroidised carbides within the bainite. It also shows a 'foreign' particle (arrowed) and associated cavities (arrowed).

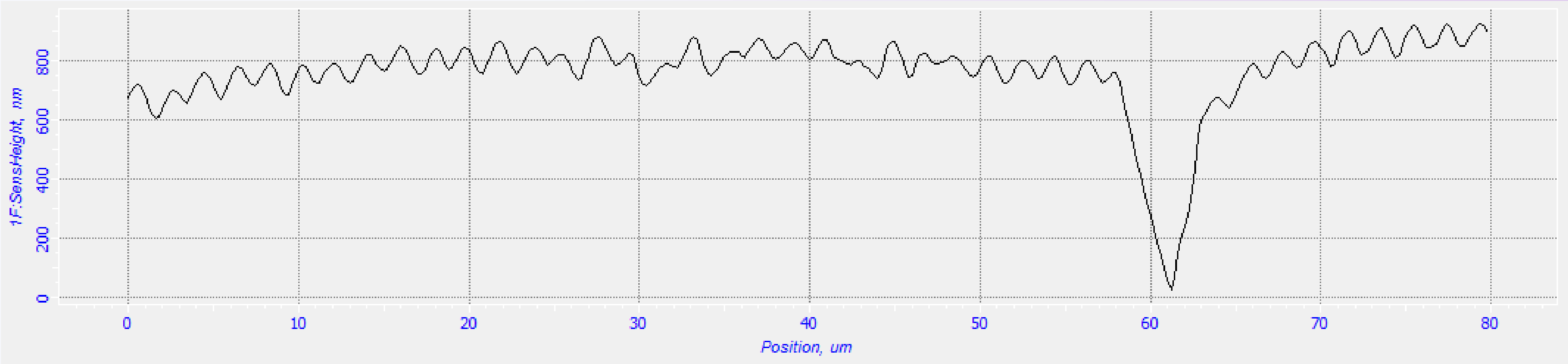




Analysis of image line profile showing possible cavity

Scanning Force Microscope [4/4]





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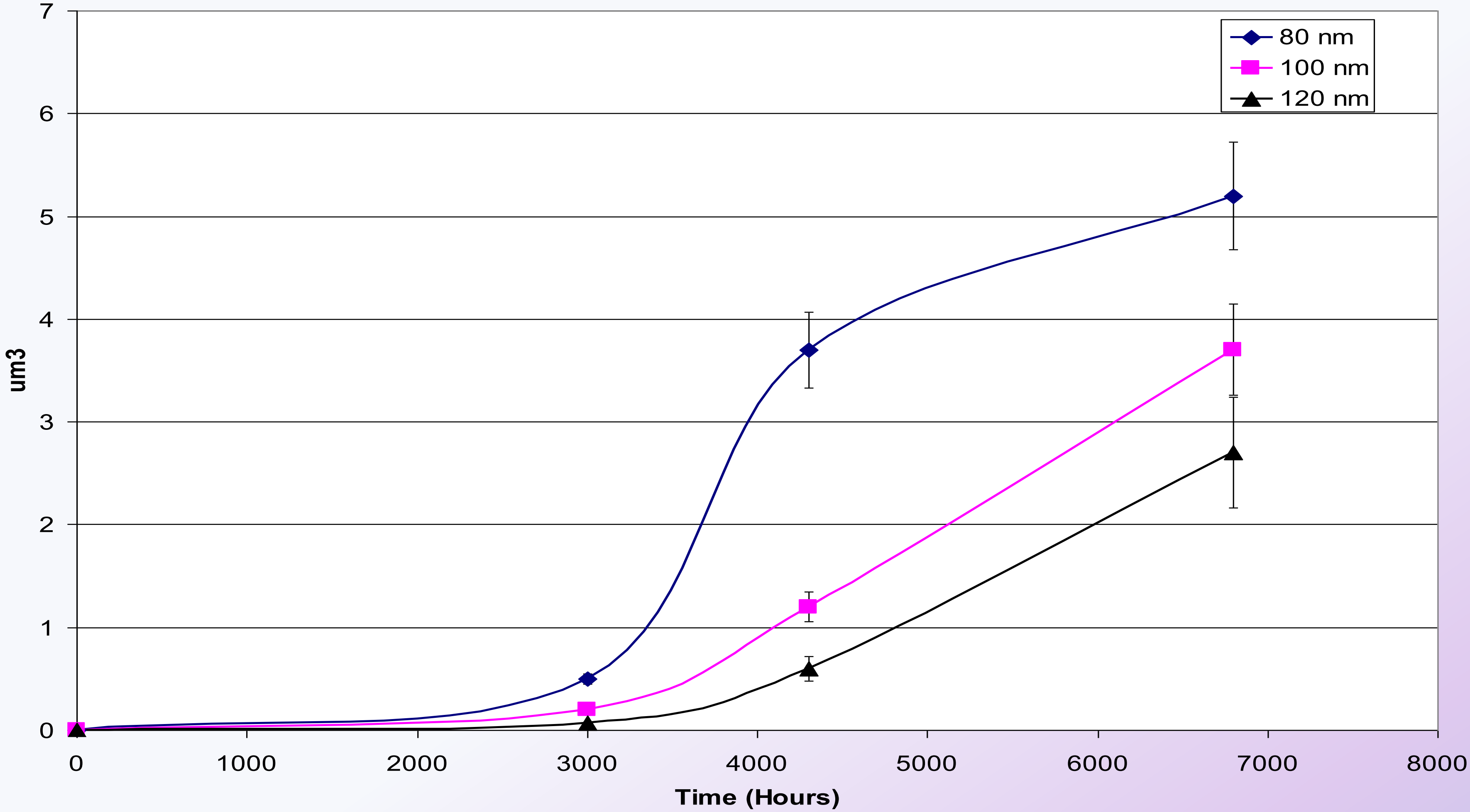
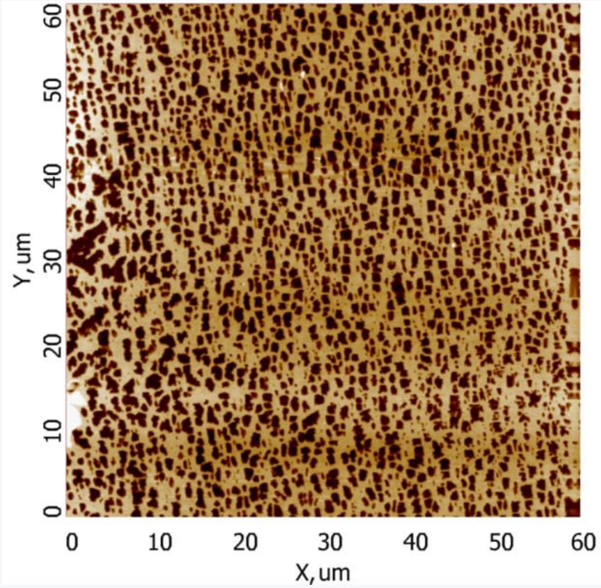


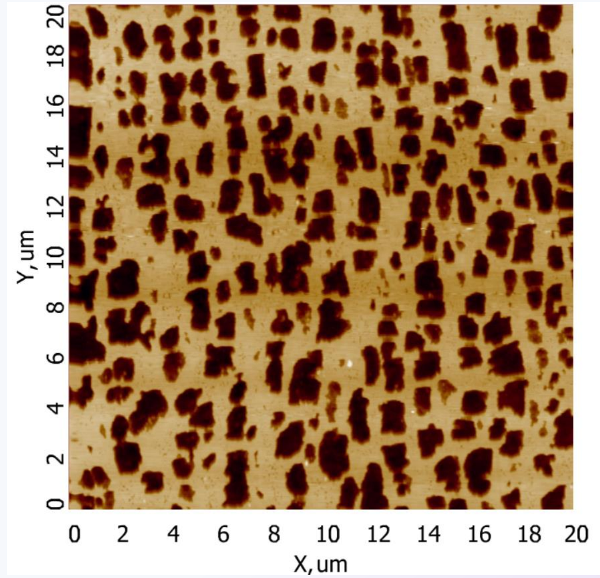
Volume of creep cavities (um3) in a 9Cr martensitic pressure vessel steel at 30%, 45% and ~70% of calculated service life of 10,000 hours

Use of SFM for Gamma Prime Study and Integrity/ Life Assessment of GT Blades

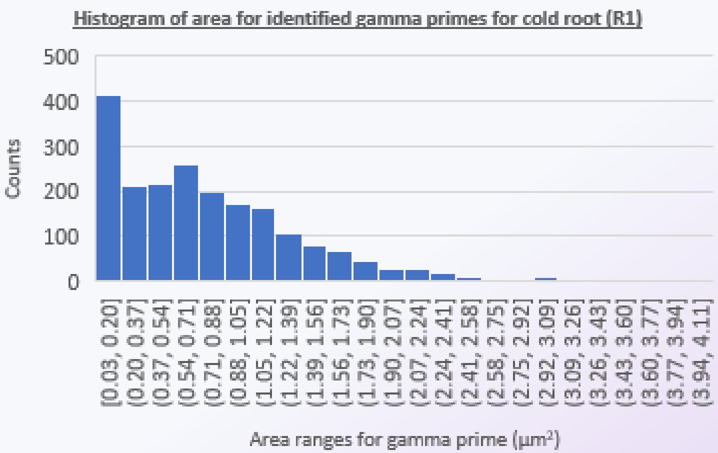
- ETD has now launched a **Group Sponsored Project (GSP)** for the in-situ study of GT blades for their safe remaining life.

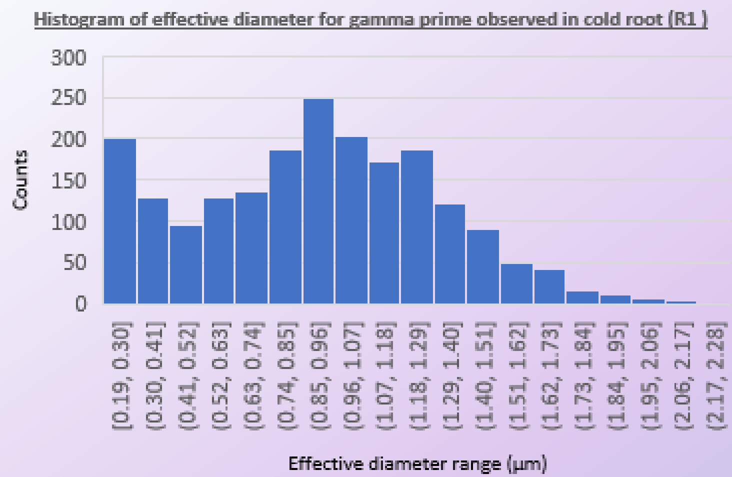
- This will be quite revolutionary in that at present the only way to study the size and shape of gamma prime involves destructive analysis. GT blades are costly so the use of SFM can help to save them from wastage.





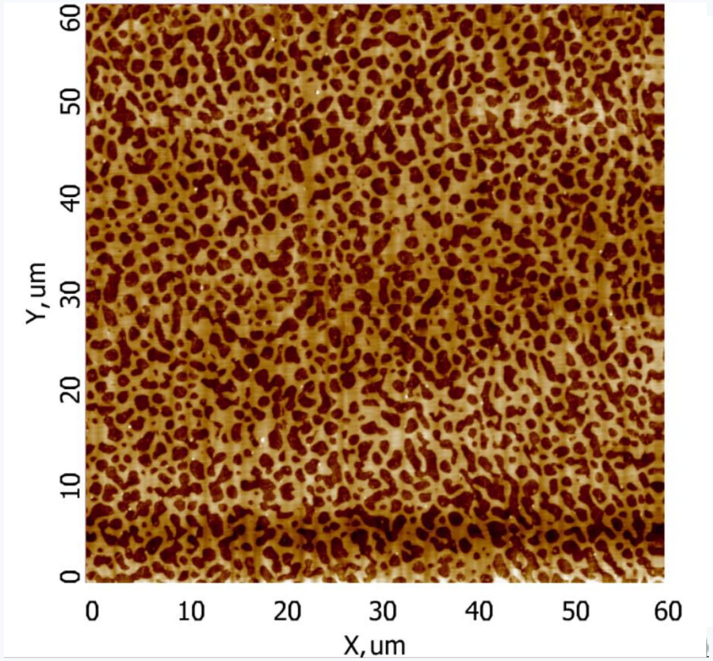
*S*FM micrograph of cold root

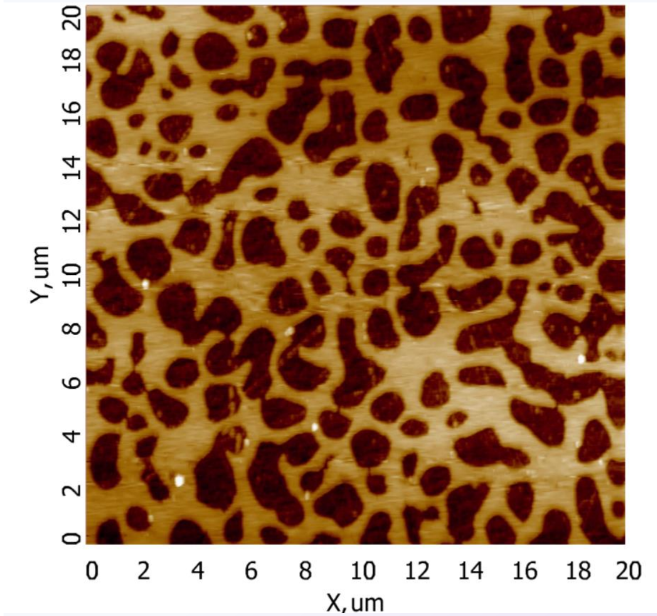




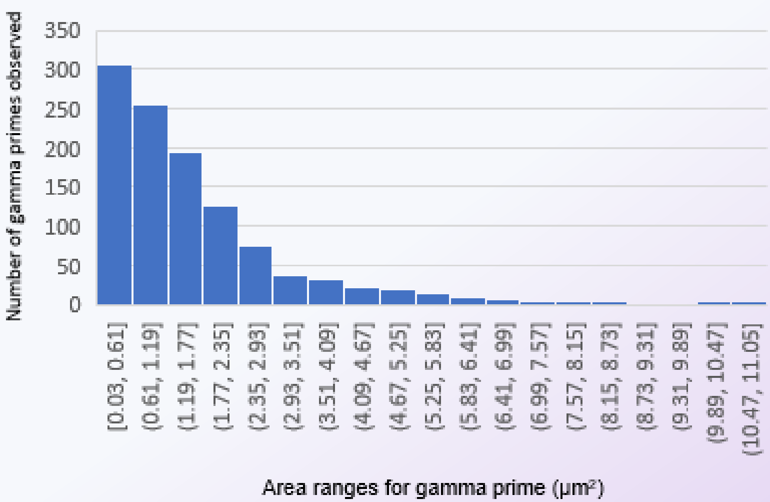
Histogram of area observed for gamma primes identified in cold root R1 region

Histogram of effective diameter observed for gamma primes identified in cold root R1 region

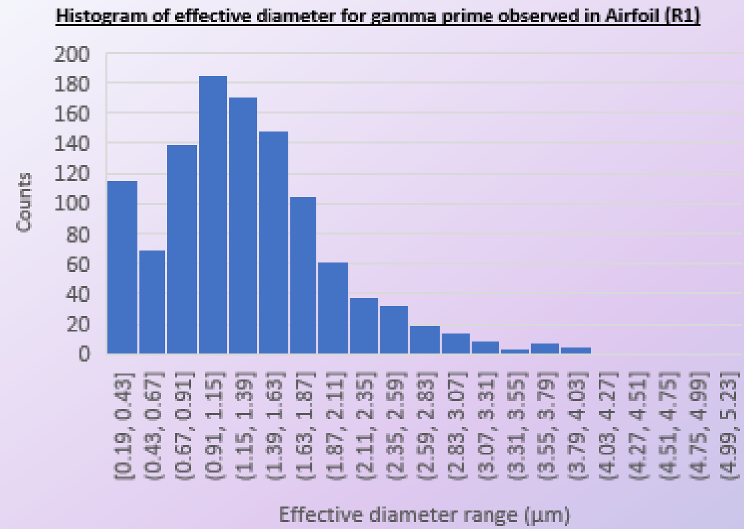




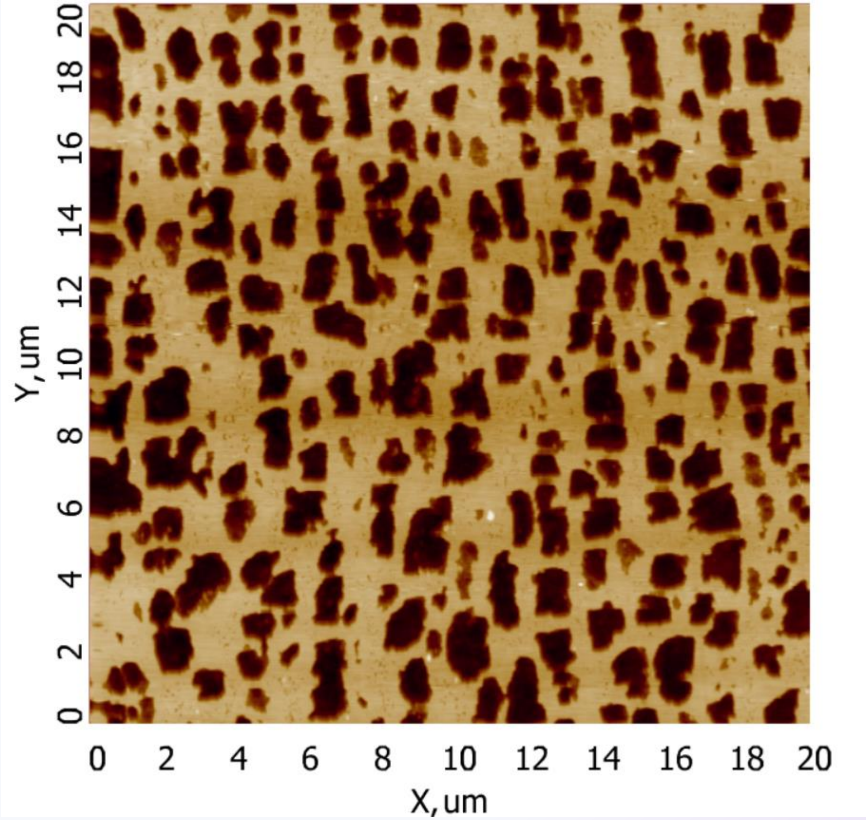
SFM micrograph of Airfoil



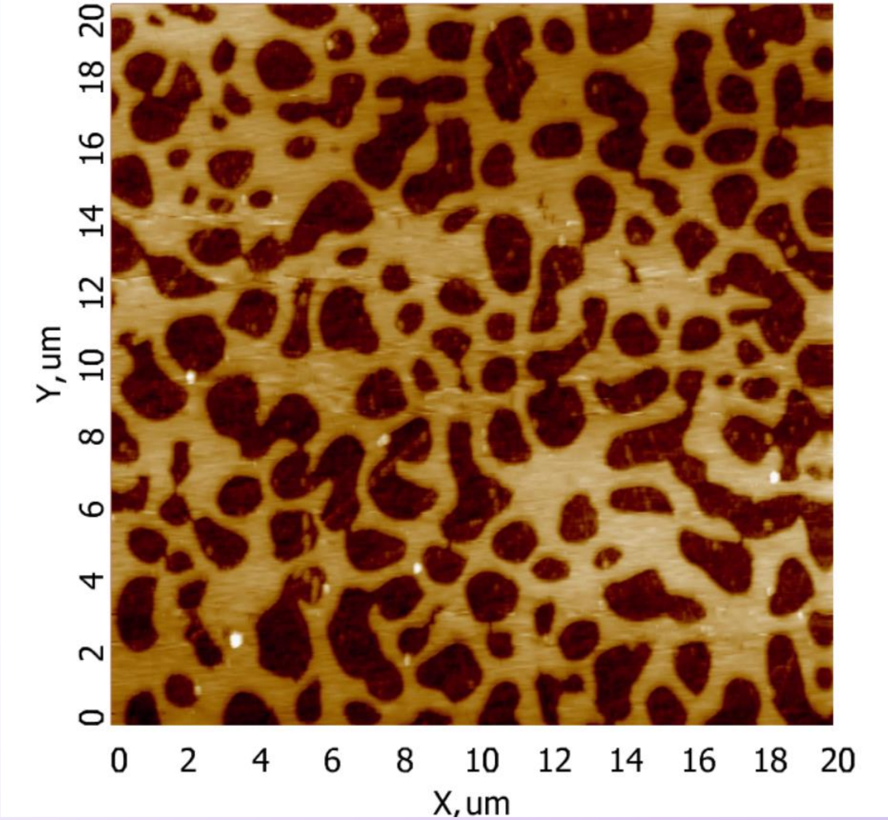
Histogram of area observed for gamma primes identified in Airfoil R1 region



Histogram of effective diameter observed for gamma primes dentified in Airfoil R1 region



Cold Root Run



Aerfoil

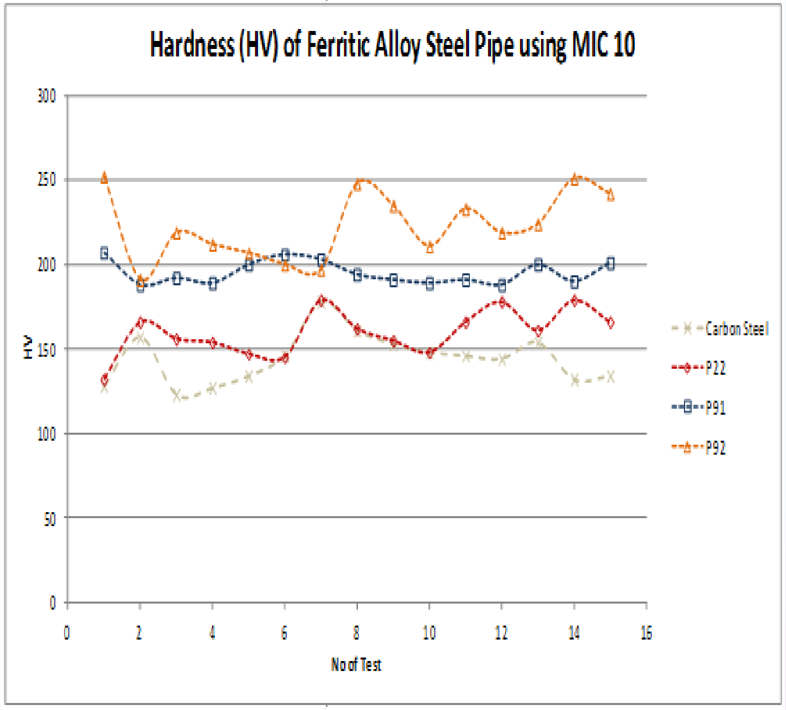
SMART SLEEVE

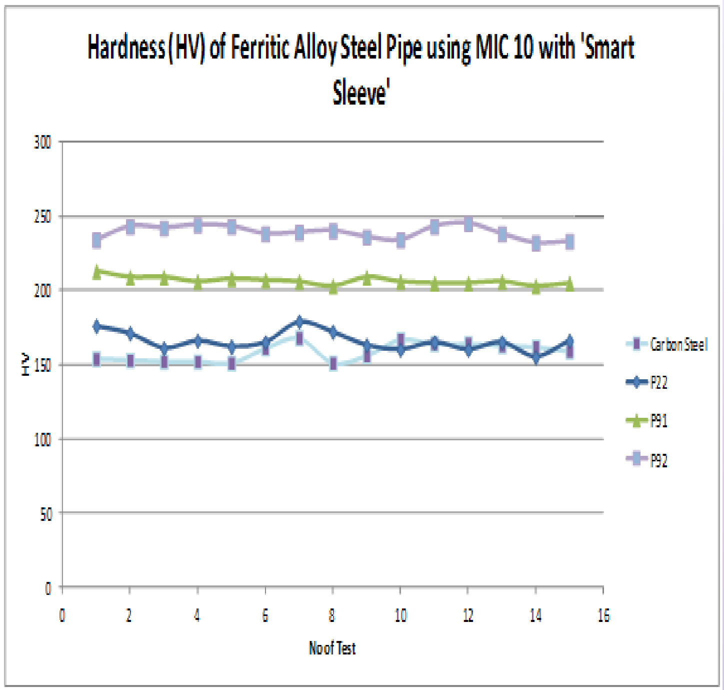
For

In-situ <u>Precision</u> Hardness Testing

MIC 10 hardness tester

Smart Sleeve – ETD's portable hardness tester

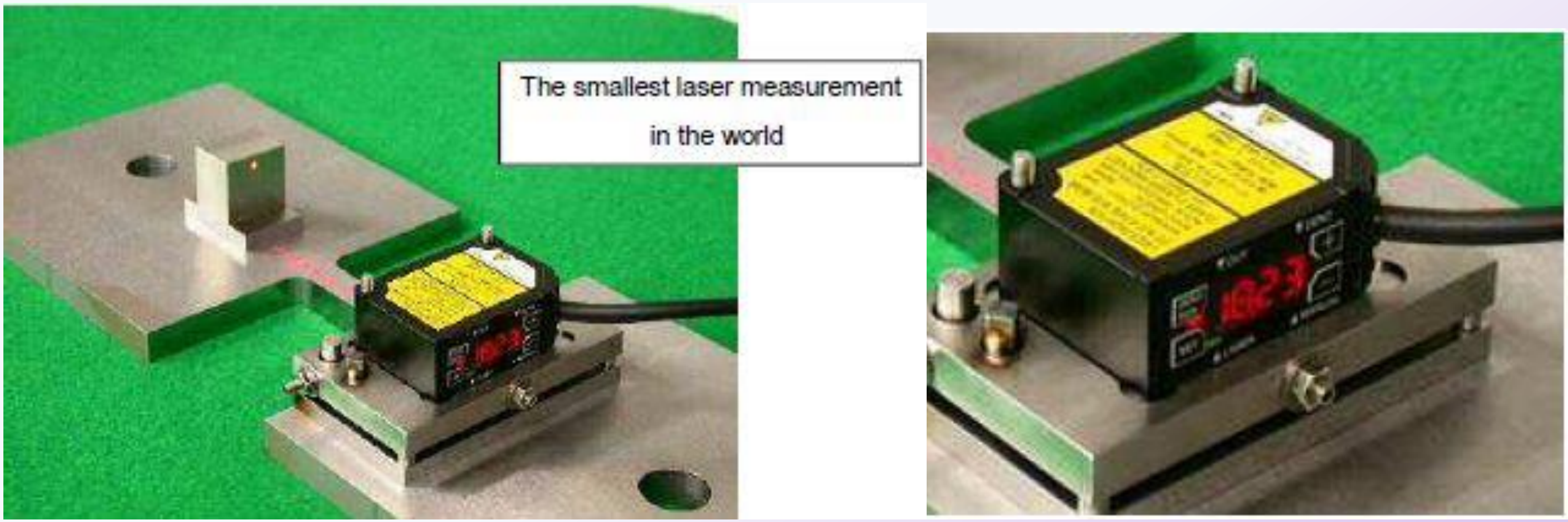




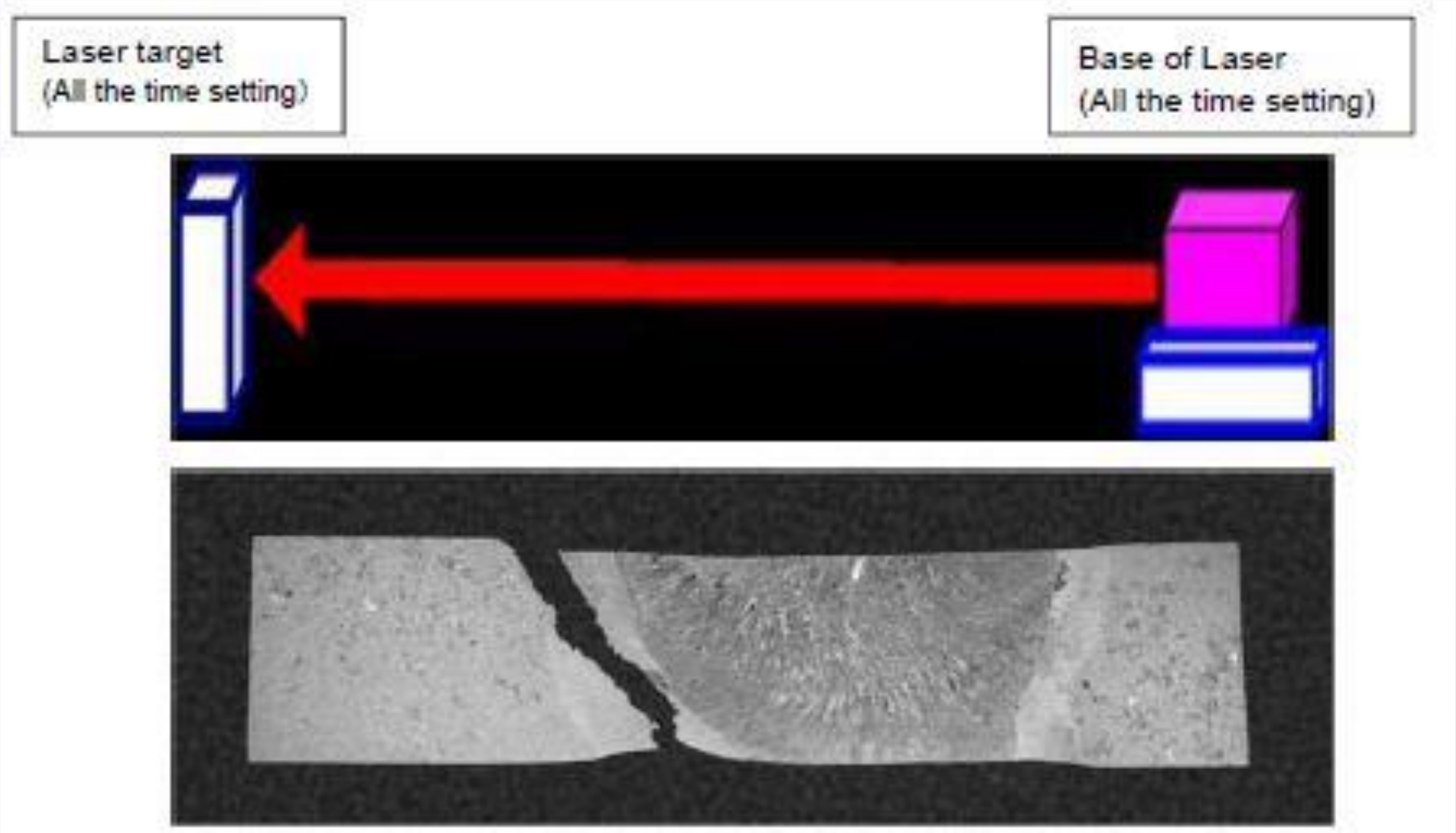
Results of hardness on ferritic alloy steel pipe, (Carbon Steel, P22, P91 and P92) using MIC 10 and MIC 10 with 'Smart Sleeve'.

Laser Strain Gauge (LSG)

for Strain Monitoring of
High Temperature Components
(during outages)



Images of LSG in use on a laboratory test piece



Schematic of in-service strain measurement method

Calculations of Strain Rate and Life Assessment

- The strain rate is calculated based on measurements made using LSG at successive outages.

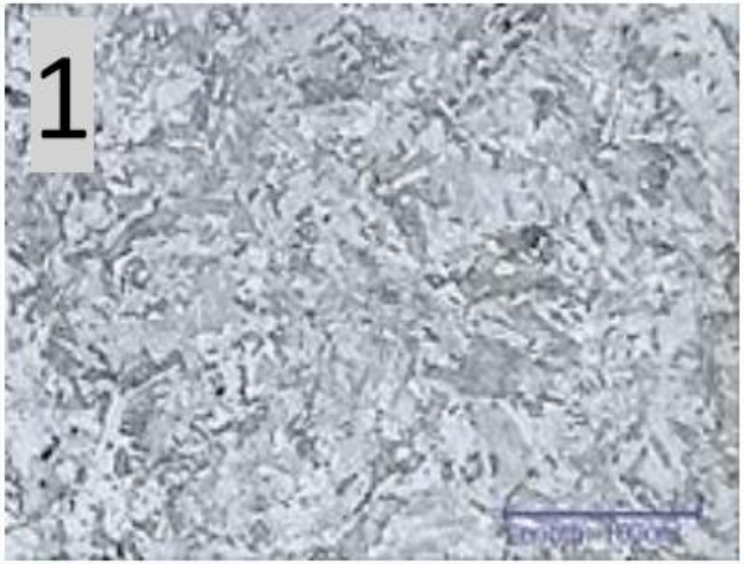
- The remaining life of the component is calculated using appropriate published relationships linking the strain rate to the creep rupture life of the material.

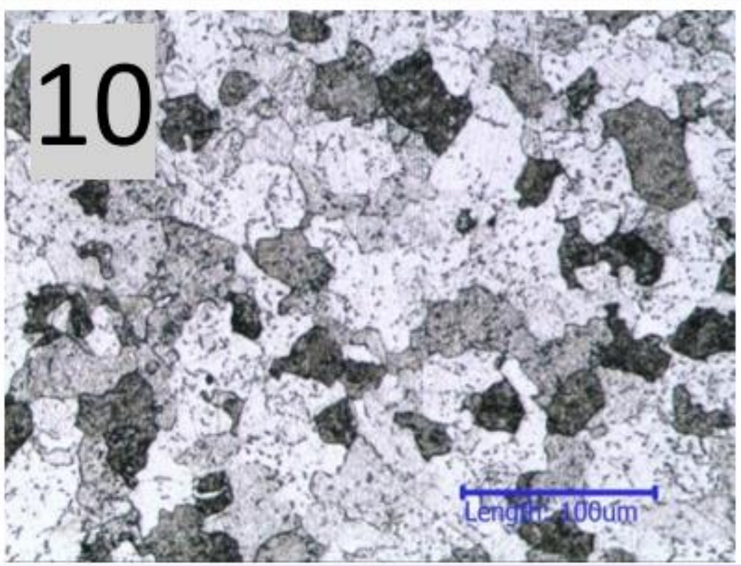
MAGSCAN
(Electromagnetic Sensor)

- **MAGSCAN → for rapid component scanning to detect aberrant P91 & P92 materials.**

- **Once the aberrant areas/ zones are identified, they may be replaced to avoid any further failures in power plants.**

Normal and aberrant Grade 91



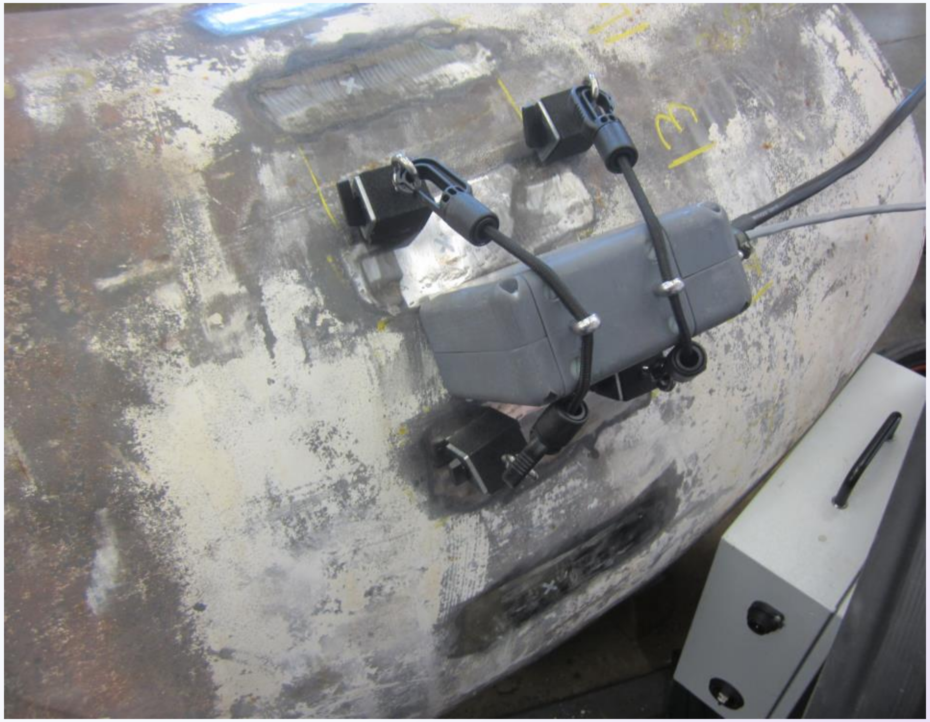


197 HV **163 HV**

- **These two are the typical examples of normal and aberrant P91. The microstructure on the left-hand side and the right-hand side of the sample are normal and aberrant Grade 91.**

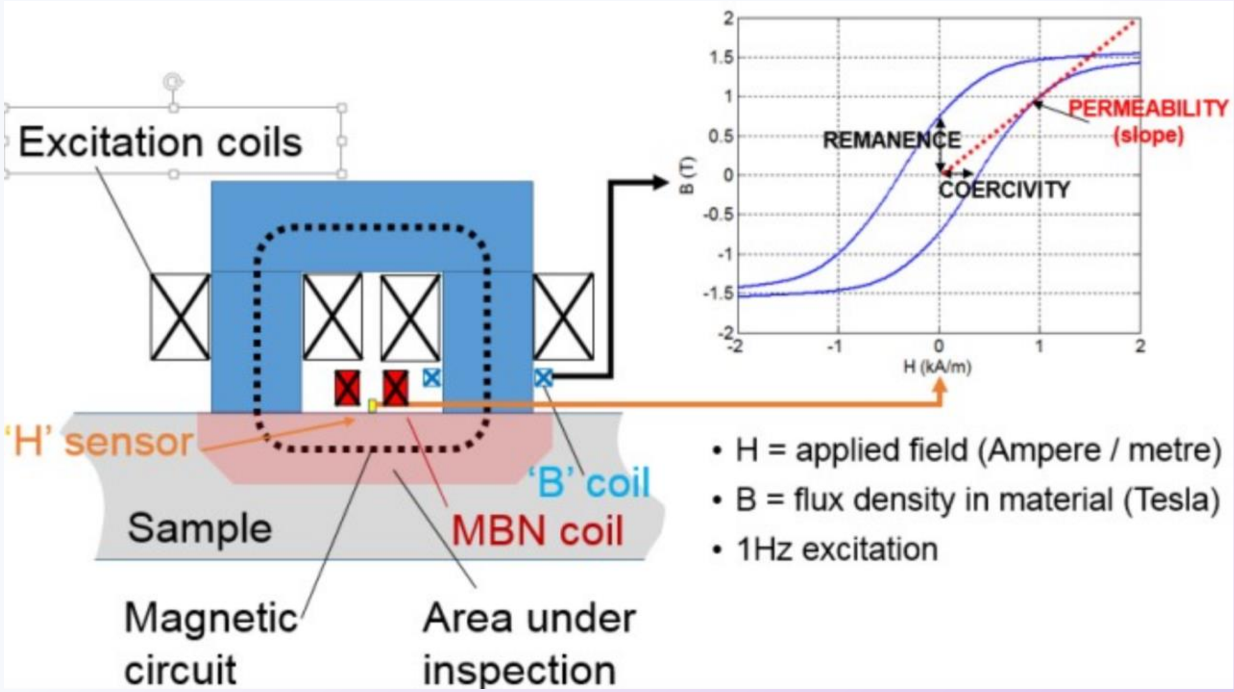
- **The differences in hardness values play an important role in component failures. There is a need to detect the aberrant Grade 91 quickly in the components to avoid further damages.**

Equipment set-up



- The equipment can be mounted in fixed positions around the pipe by permanent magnets and scan the target regions.
- The scanning results can be read instantaneously.
- Two frequency modes can be operated: 1 Hz and 0.1 Hz.

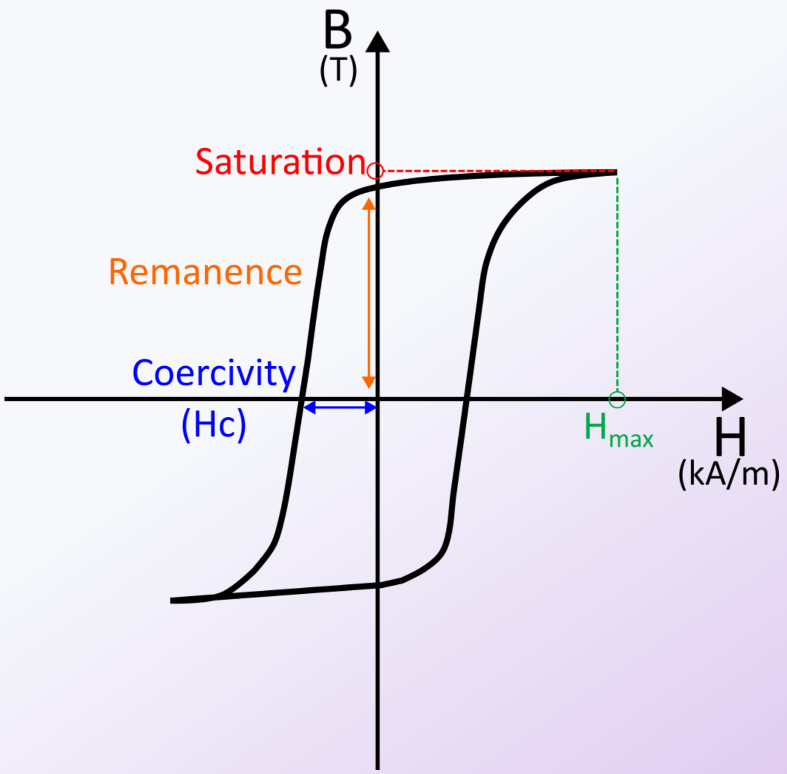
EM sensor



Using magnetic response of the test material can then be correlated with the microstructural parameters.

Common parameters used in B-H loop

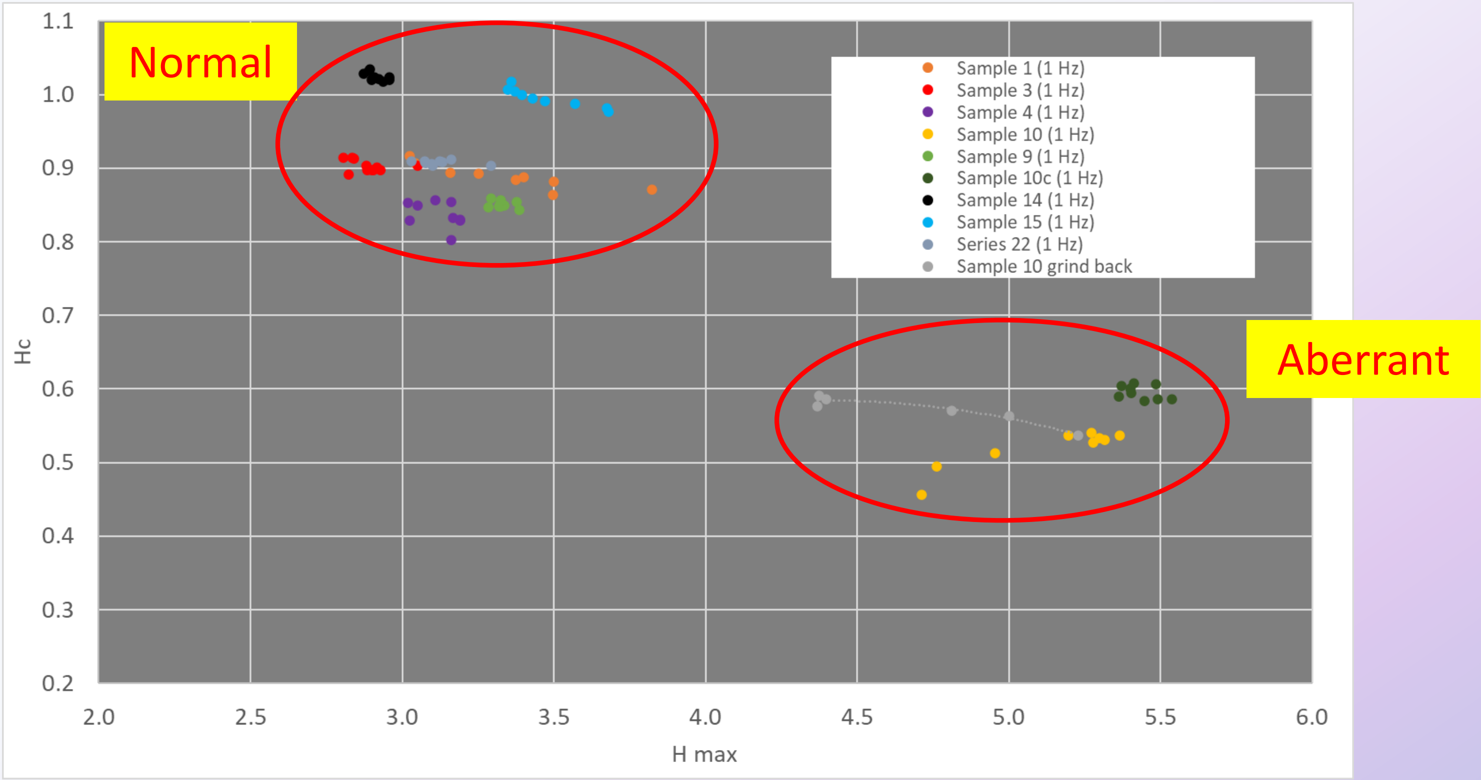
B: induced magnetic flux density
H: applied magnetic field



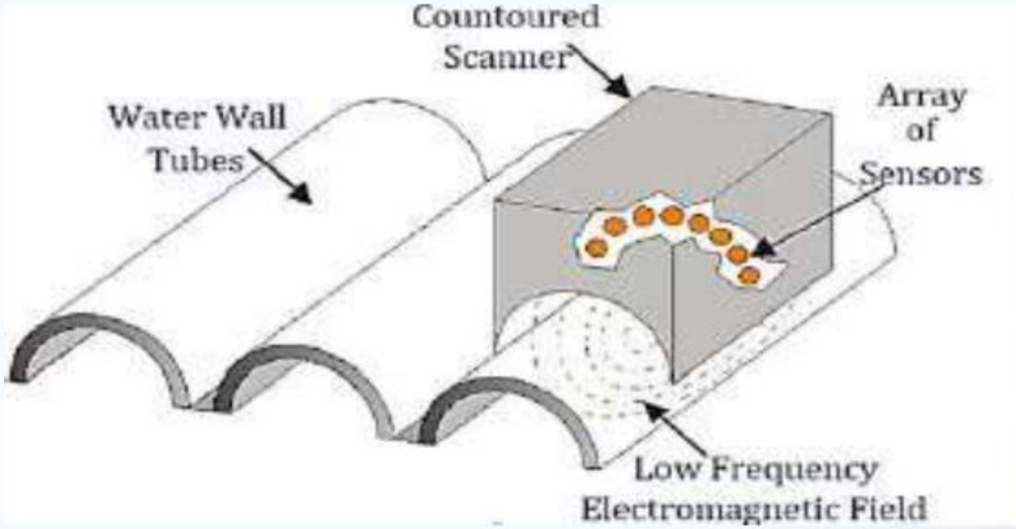
The four parameters in the B-H loop are the most common results to compare with different regions.

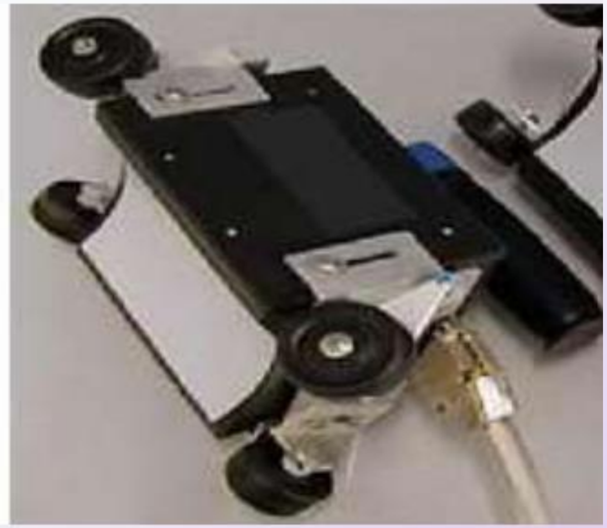
Distinguish between normal and aberrant Grade 91

1 Hz scan



Low Frequency Electromagnetic Technique - LFET





- LFET system provides 100% scanning of the tube for the detection of any thickness variation at a fast speed of 3 to 4.5 meters per minute.
- No need for any couplant; requires only moderate cleaning.
- Suitable for detection of pitting, general wall losses, caustic and phosphate gouging, hydrogen damage, FAC.

Balance Field Electromagnetic Technique BFET

BFET is based on eddy current principles.

- **Fast scanning technique <u>for crack-like indications</u>.**
- **Replace laborious techniques such as dye penetrant or magnetic particle inspection.**
- **Minimal surface preparation.**
- **Scanning speeds up to 30 cm per sec.**

Typical ETD project scope

- Wall tubes in hopper area.
- > 500 tubes.
- Tubes scanned from top to bottom over a length of about 1.8 meters.
- 3 scans per tube.

BENEFITS of LFET & BFET

Conventional UT inspection:

- Time-consuming, spot checks
- Cleaning & surface preparation.

LFET & BFET:

– Far rapid inspection.
– Continuous scanning along surface, not just point measurements, more coverage.
– can find localised damage.
– Suspect locations can be checked by UT.

Long term continuous PD monitoring of high temperature pipework and welds for creep damage warning

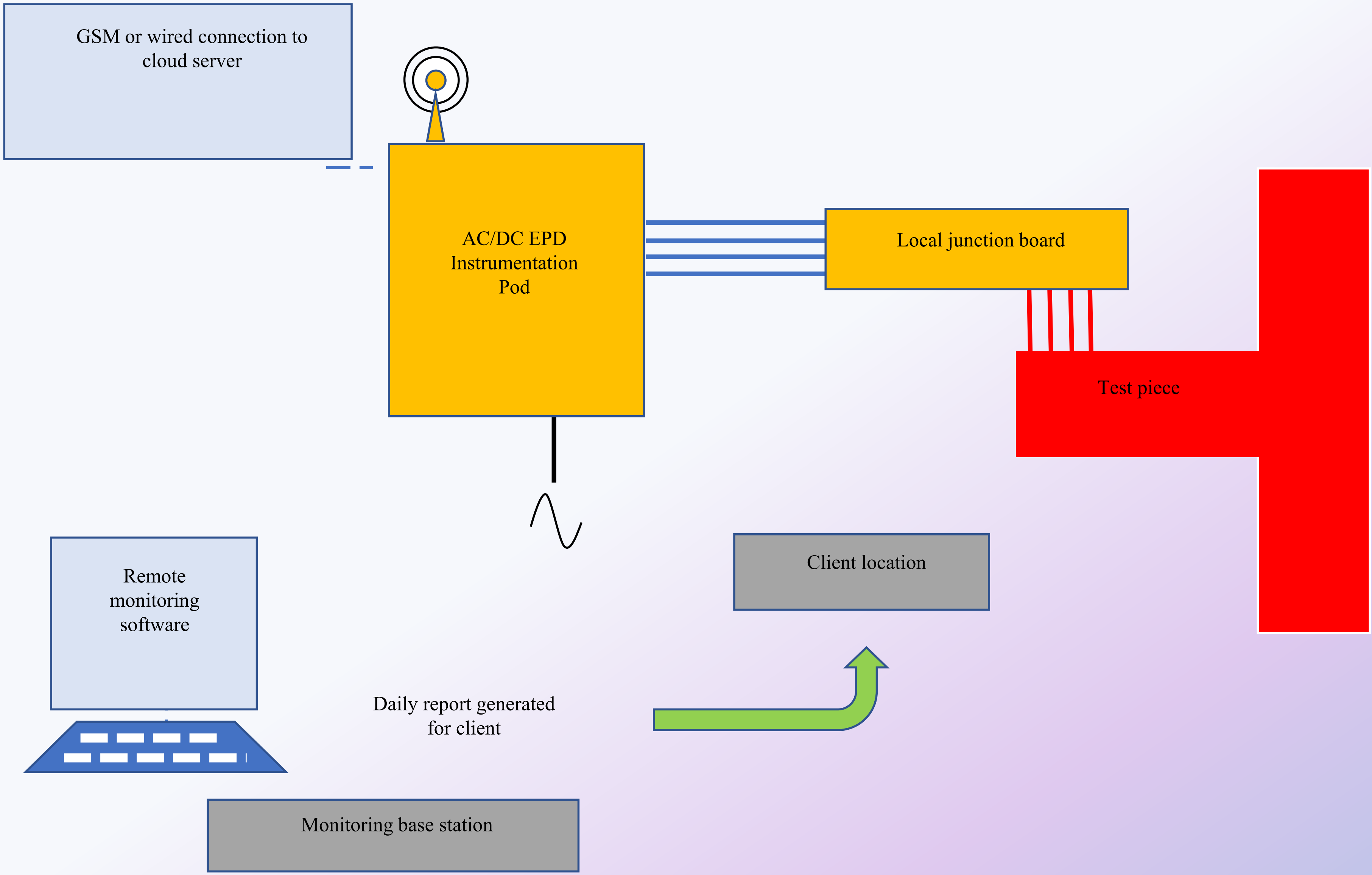

GSM or wired connection to cloud server
AC/DC EPD Instrumentation Pod
Local junction board
Test piece
Client location
Remote monitoring software
Daily report generated for client
Monitoring base station

Figure 5. DCPD plot for zone containing a developing creep crack on the P91 vessel of Figure 1. Rising curve was for crack site HAZ, whereas falling curve for adjacent non-cracked HAZ. (x-axis represents 1 month approx.).

Thank You

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