Further Developments in Inspection and Monitoring Techniques for High Temperature Plant

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ETD
IN BRIEF

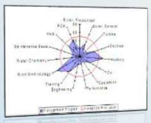
- Engineering & R&D company based in Leatherhead, Surrey (south of London), UK
- For Power & Process Plant Owners/ Operators, Manufacturers and Service Providers

Specialist Institutions → Research → ETD ← Knowledge ← International Experts

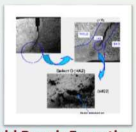
Application

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

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

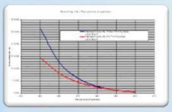


RBI, RBM, FFS



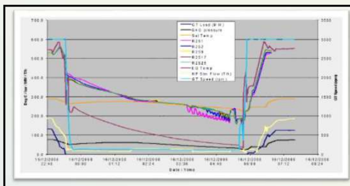
Weld Repair Expertise

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



Crack Assessment (RLA, FFS)

Stress Analysis – CAESAR Pipeline Stress Analysis / FEA



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

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

Use of P91 & P92 (9% Cr) martensitic steels in:

a) Conventional power plant, and,

b) HRSG thick section components

is now very common

This Presentation in 2 Parts

(based on two Group Sponsored Projects)

1. **Heat Treatment issues giving rise to Aberrant or Abnormal P91**

2. **New Inspection Techniques for early stage damage detection**

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Project 1 – *A Group Sponsored Project (GSP)*

(6 years duration, now in 5th year)

P91: Manufacturing, welding heat treatment + Safe Remaining Life

– involves long term creep tests (30k hours) + Metallography

Sponsors: **A group of European and Japanese Utilities**
(New sponsors can join any time)

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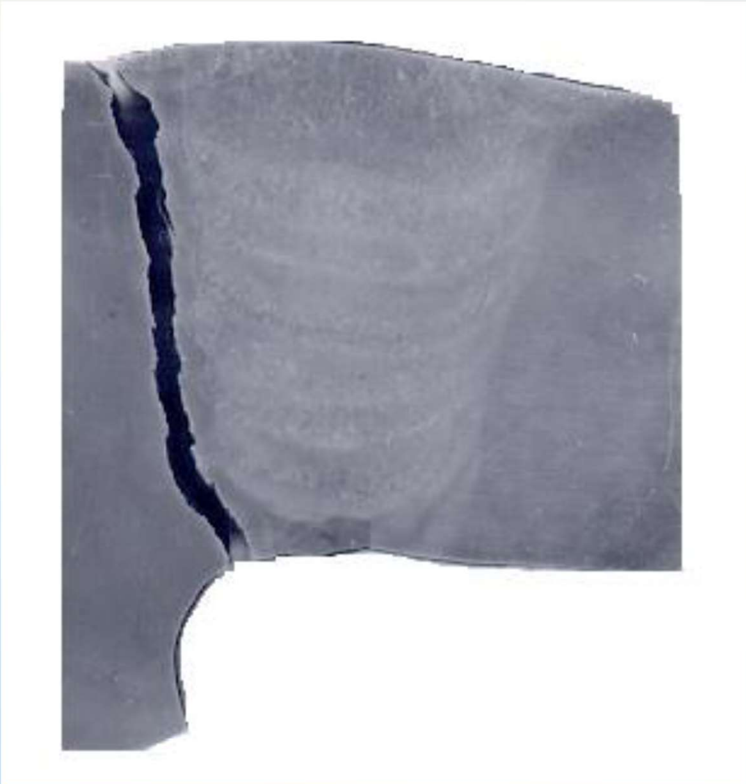
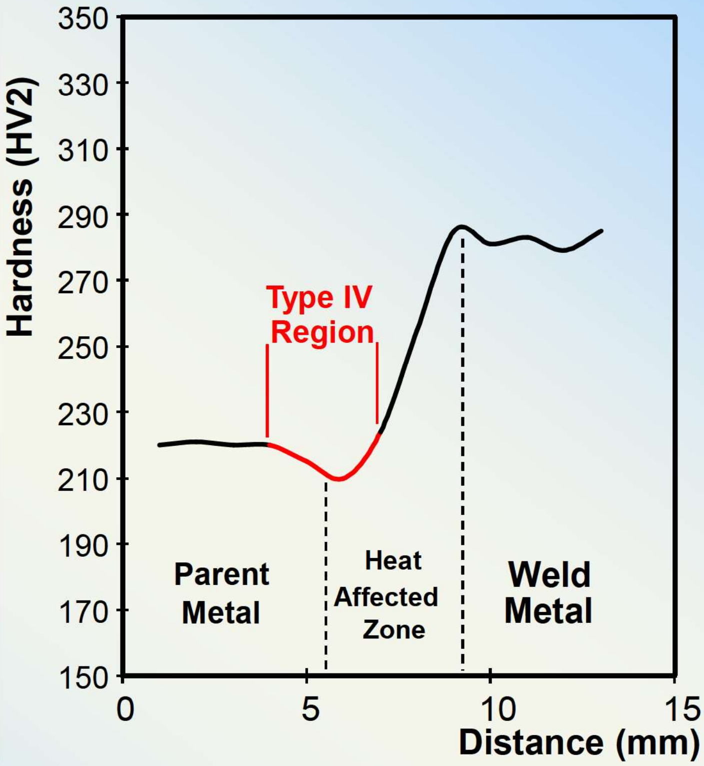
- **P91 material properties depend on the *tempered martensite* microstructure**
  - **Very sensitive to heat treatment**

- **Need to handle P91 with care during**
  - **Manufacturing**
  - **Welding**

Welding 9-12%Cr steels

Type IV Cracking





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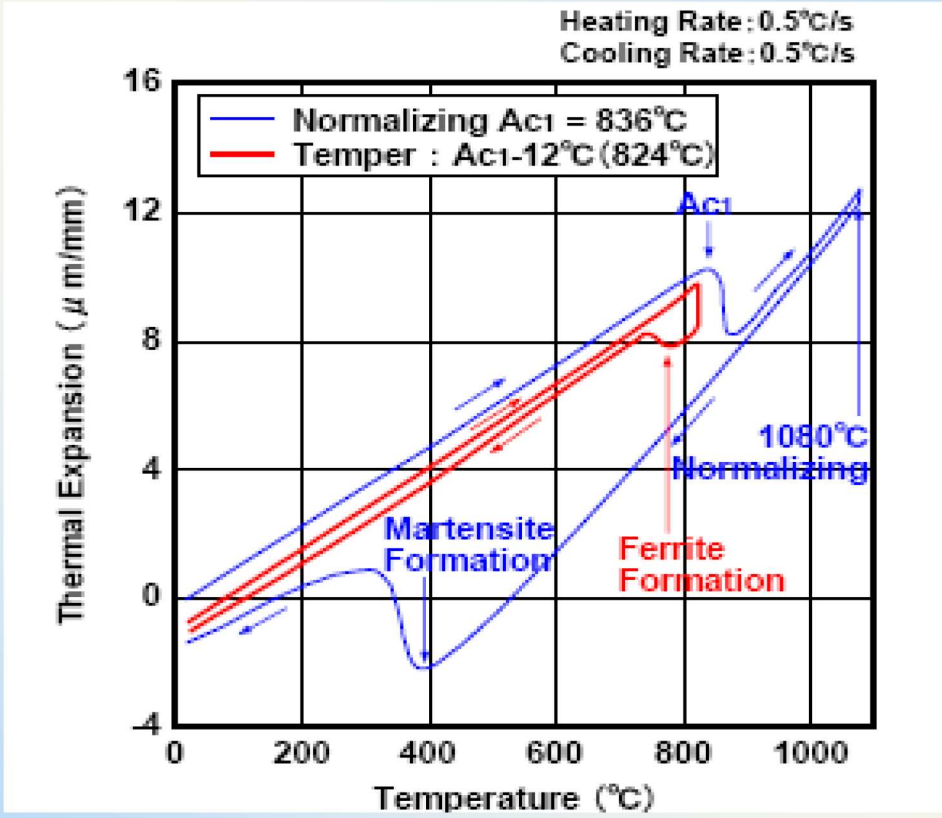
Ref: S. J. Brett, "In-Service Failures of Modified 9Cr (Grade 91) Components," IMechE Seminar - Forensic Investigation of Power Plant Failures, One Birdcage Walk, London, March 2, 2005.

Type IV cracking on the F91 side of a weld between an F91 forged transition bottle and a T91 tube (48mm OD) taken from Ref [2].

Dilatometric measurement of P91



Ref: F Masuyama

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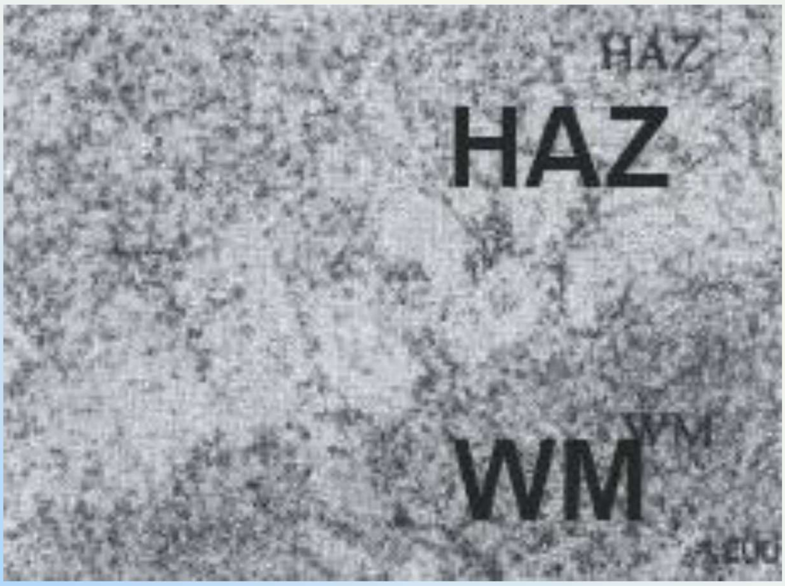
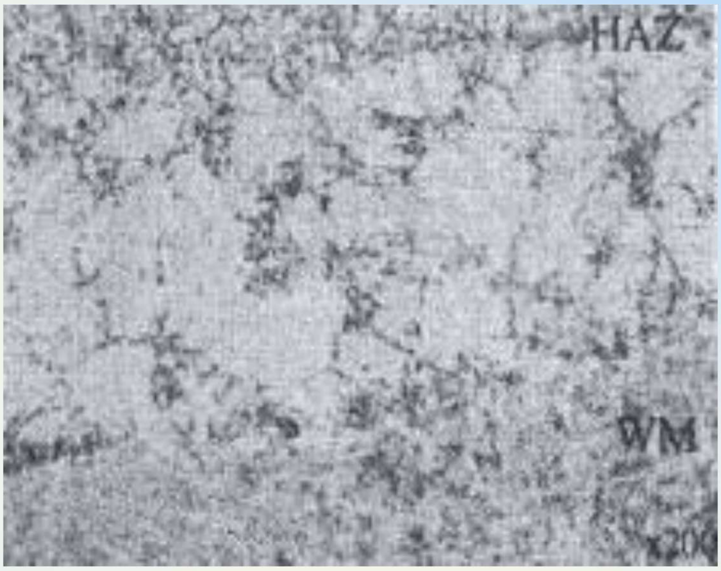
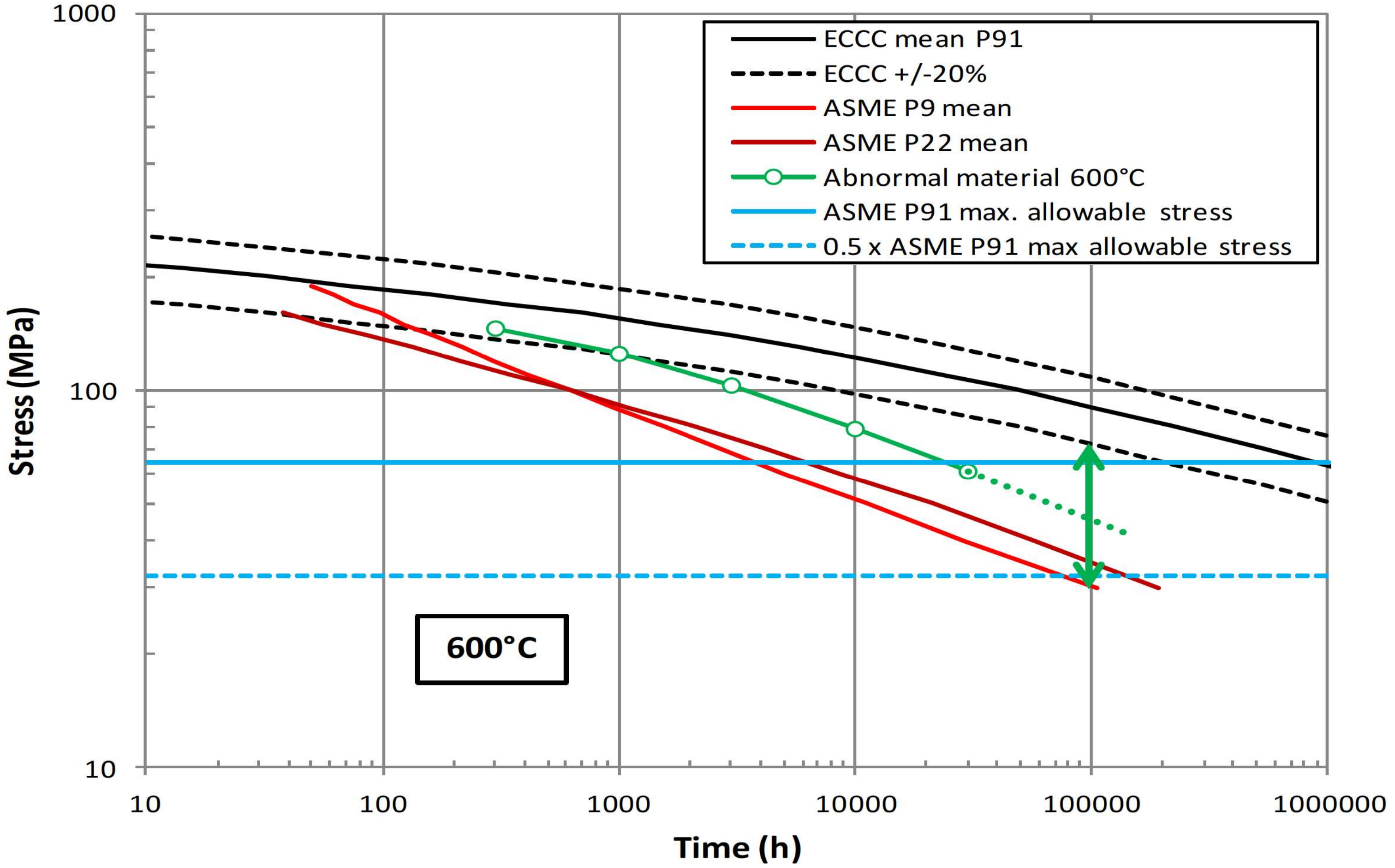
Soft spots/ bands along pipe length

Original microstructure in the HAZ was over-tempered, exhibiting some degradation of the tempered martensite and coarse carbides





‘Aberrant’ P91 (green line) may lie between P91 and low alloy bainitic steel strength



Aberrant microstructures being studied in the joint industry project 'Abnormal P91'

Parent Material	Filler Metal	PWHT
Normal	Gr.91	Under-tempered (<730°C)
Normal	Gr.91	Over-tempered at 10°C below Ac_1
Normal	Gr.91	Over-tempered at 15°C above Ac_1
Over-tempered at 10°C below Ac_1 for ~6 hours	Gr.91	Normal
Tempered at bottom of allowable range (730°C)	Gr.91	High in ASME range (775°C)
Under-tempered at 704°C	Gr.91	Normal
Fully ferritic (too slow cooling from austenitizing)	Gr.91	Normal
Mixed 30% ferrite – 70% martensite (too slow cooling from austenitizing)	Gr.91	Normal
Normal	High Ni + Mn (i.e. low Ac_1)	High in ASME range (775°C)
Normal	Gr.91	Re-normalize & temper
Normal	Gr.91	3 x repeat repair (one HAZ in BM; other in WM); normal PWHT
P91 and P22 (DMW)	Gr.91	Normal
P91 and 321 (DMW)	IN182	Normal
P91 and 321 (DMW)	P87	Normal

Project 2 *- A Group Sponsored Project (GSP)*

'P91-P92 Inspection & Lifing' .

This project dealt with **NDE** and **lifing** of **P91 welded components** and the development of new and more reliable on-site tools.

Sponsors/ Partners: **ETD**, **Nippon Steels & Sumitomo Metals, ENEL, GE, TNB, Engie, MPA**

The Problem:

- The **cavity size** in 9Cr martensitic steels for up to about 70% of component life can be of nanometre level only.
- Thus cavity detection and quantification by traditional means can be difficult until late in life.

Inspection & Life Assessment Problems

To make matters worse and life assessment difficult in P91 and P92 steels creep failure stages are reduced to:

- Creep cavity initiation → cavity growth → failure with little warning.
- No spherodisation.

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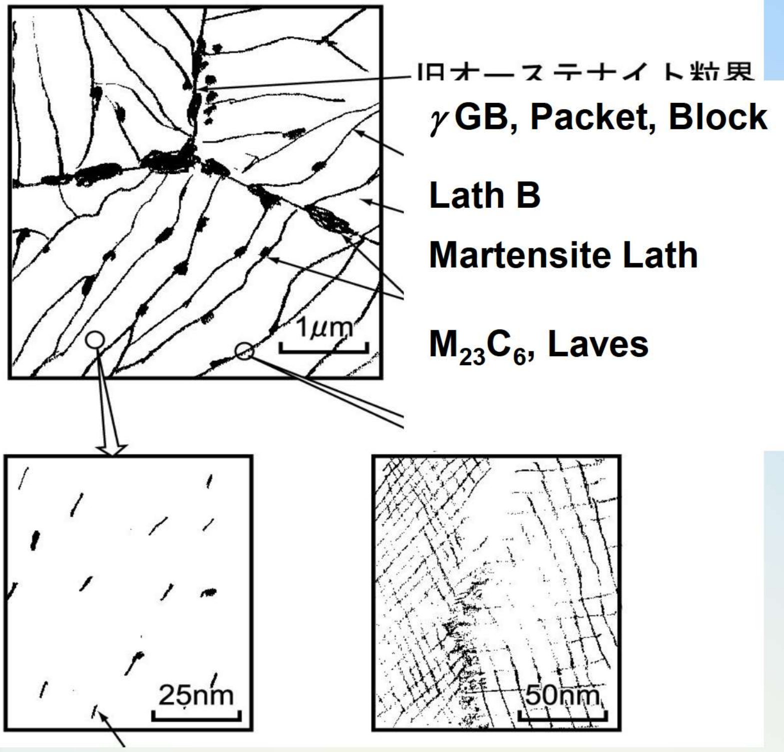
Typical Microstructure of Martensitic 9-12%Cr Steel (Matrix, Precipitates, Dislocation structures)

a) OM



MX Precipitation in Grains

Dislocation Network Lath Boundary

b) TEM

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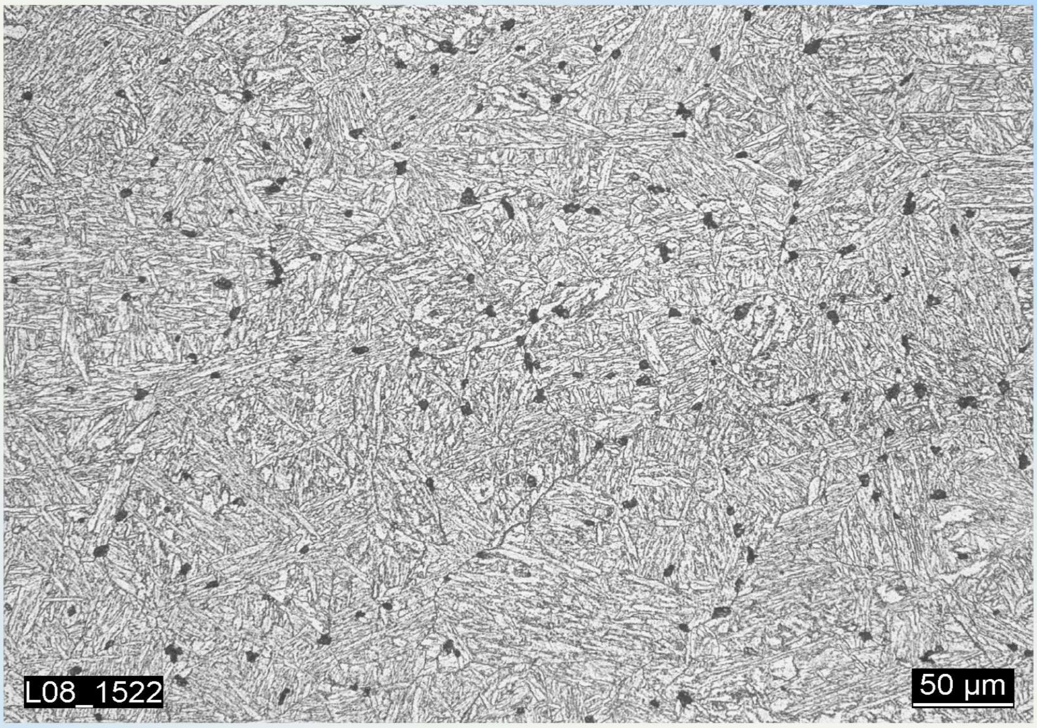

E911, 600°C, t/t_F= 1,
t_F=32000 h, 167 C/mm^2

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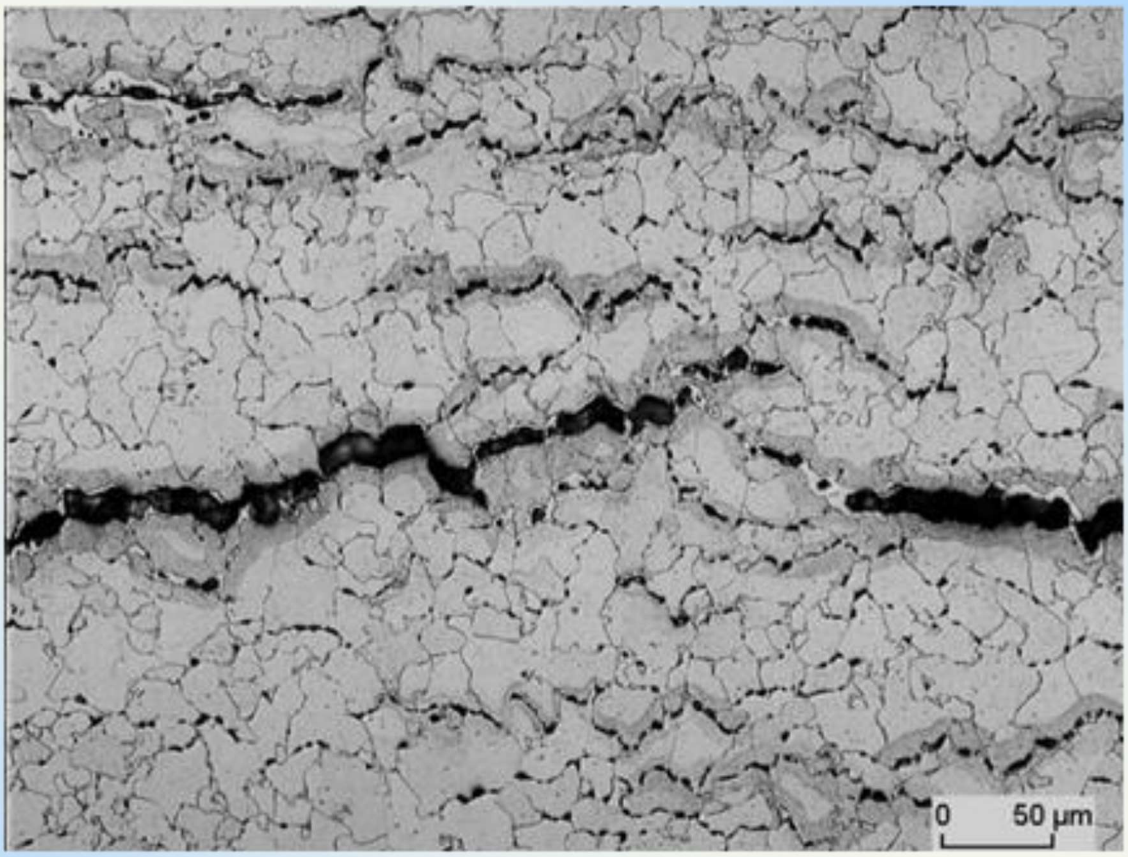

Macrocraking in a **low alloy steel** and the final fracture

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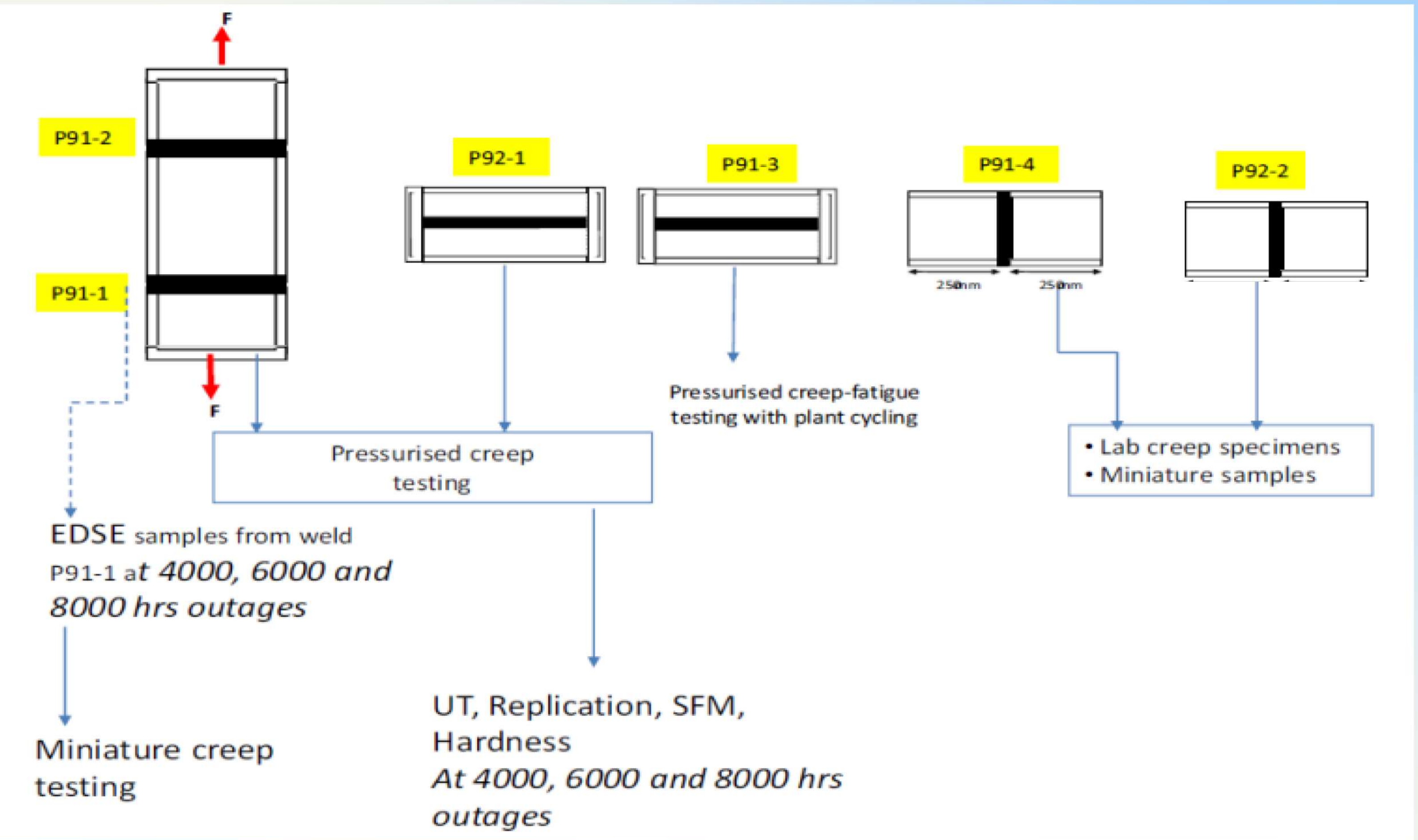

Schematic diagram showing the P91 and P92 welded pipes & testing being conducted in this project

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P91 pipe with two butt welds being tested at temperature, under pressure and end load to simulate system loads

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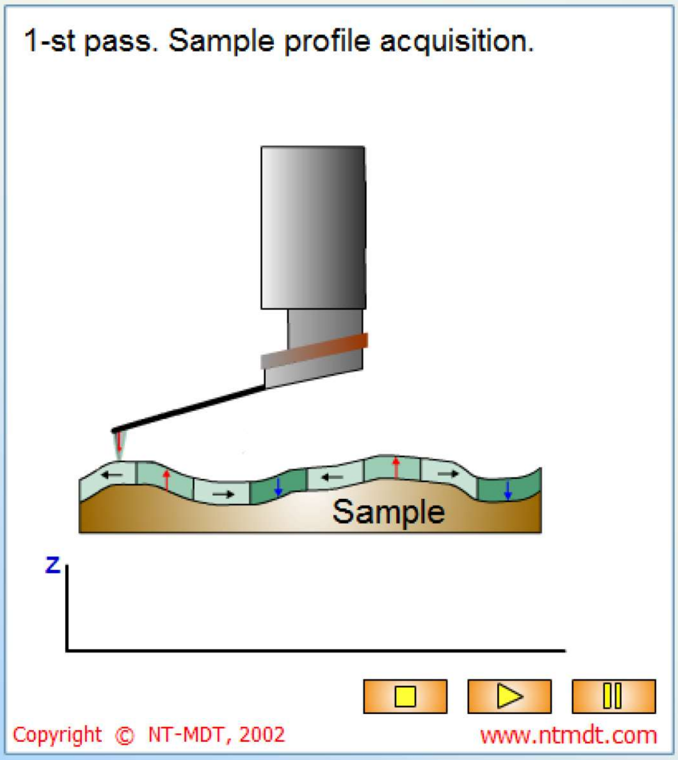
- Testing of these feature specimens was stopped at ~**30, 50, and 70%** of the estimated life of **10kh** at 600 and 625C.
- **New NDE** techniques were developed and used to quantify damage & relate to remaining life. **FE analysis** was performed to develop RLA relationships.
- **'Slice samples'** using EDSE were cut out from some of the test welds during the outages to relate damage detected by the NDE techniques to the real damage.



Portable Scanning Force Microscope (SFM) - principle of operation

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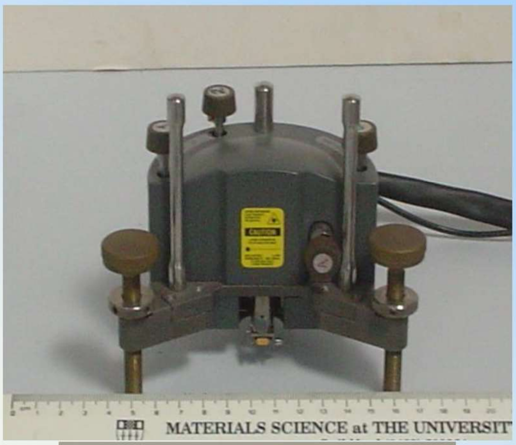

Scanning Force Microscope. From top left hand (clockwise) – Lab version, portable version, portable version hand held, Portable version in use on a pipe ring

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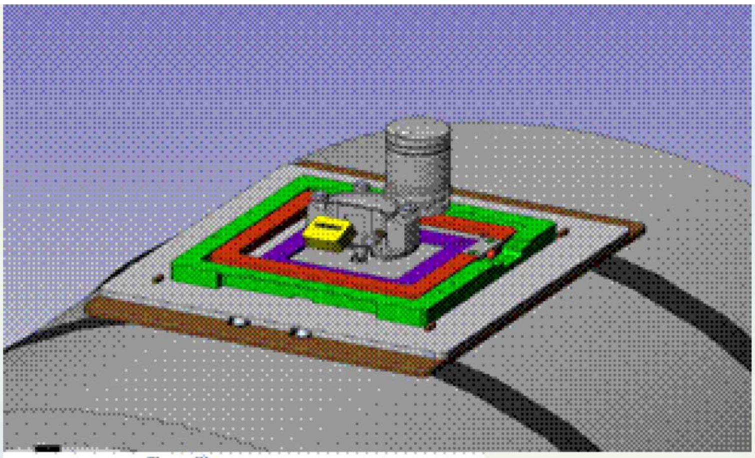

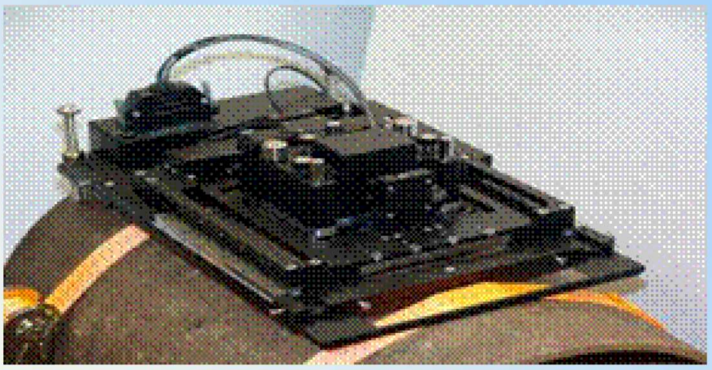

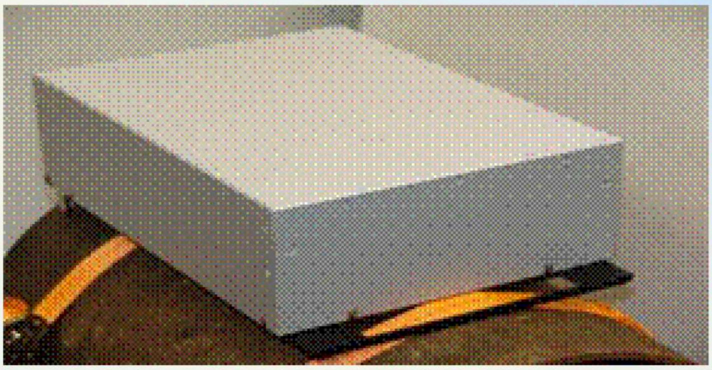

New SFM with the mounting frame. Clockwise from top left: Schematic with the mounting frame, SFM mounted on a horizontal pipe, SFM enclosed in a box for safe keeping in plant during use, SFM mounted on a vertical pipe

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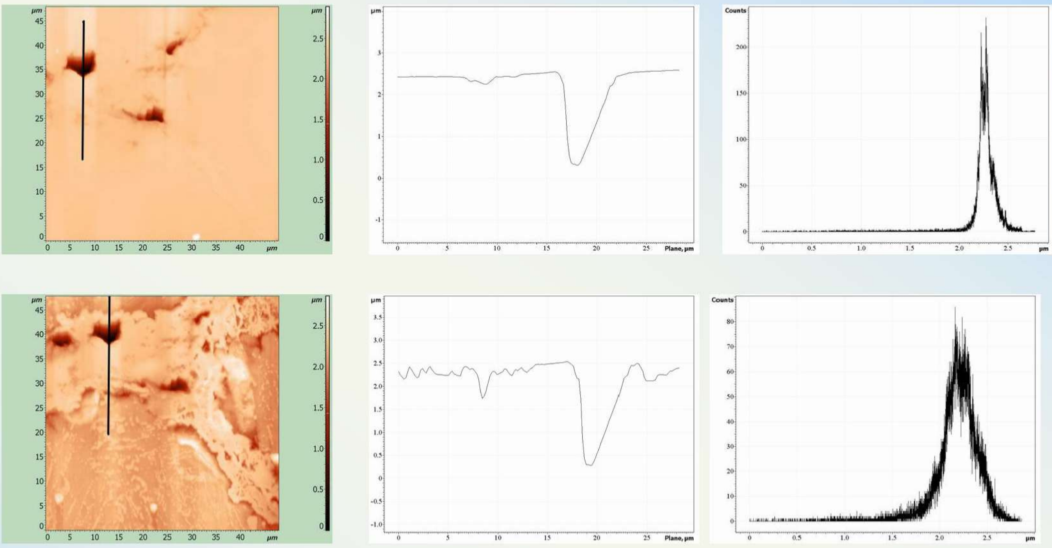
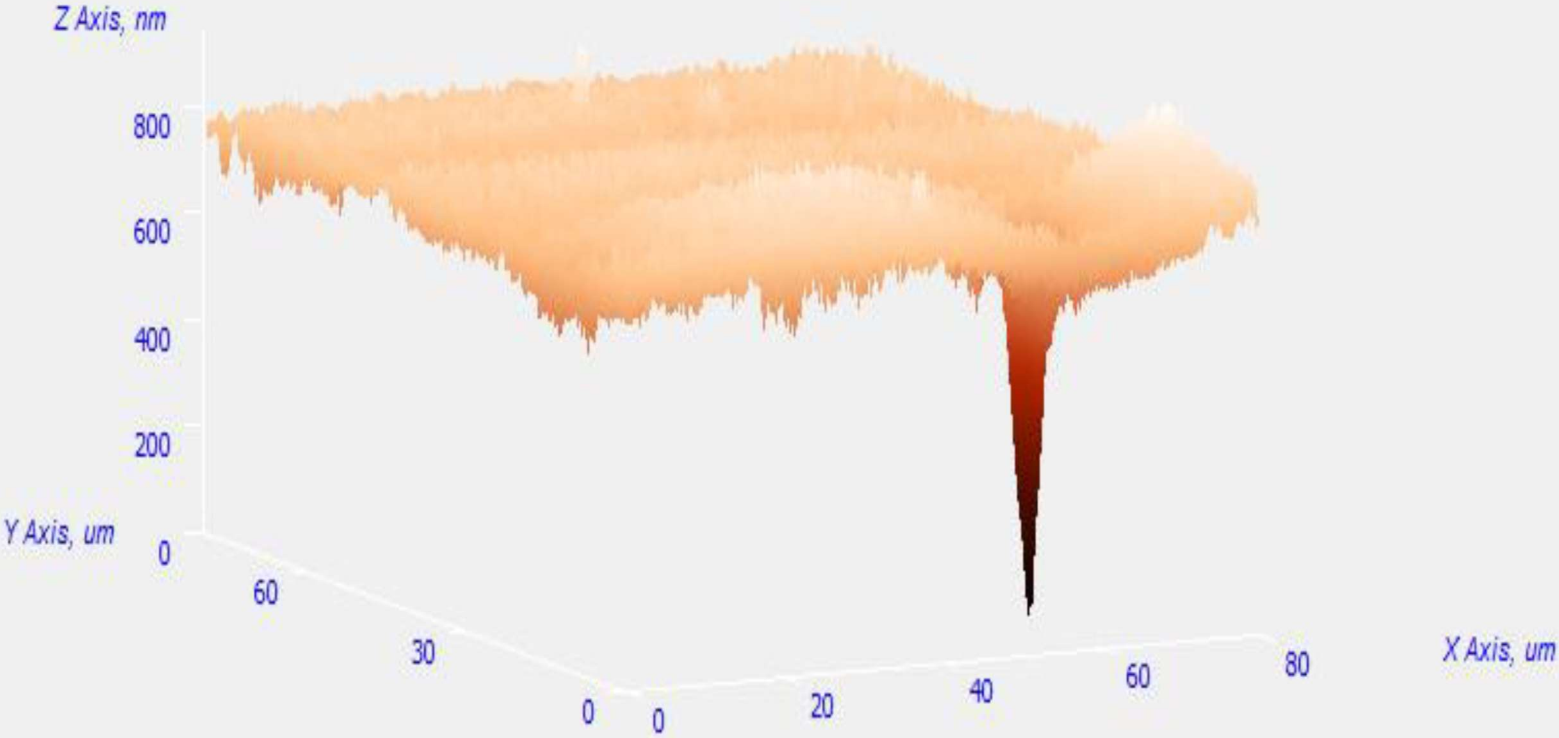


Figure.12. SFM images acquired before and after chemical etching for 2 minutes. Height data and depth distribution curves are shown at the right side. Increase of the half-width after etching is determined by surface roughening during etching

Three dimensional SFM image of the P91 pipe showing the cavity depth



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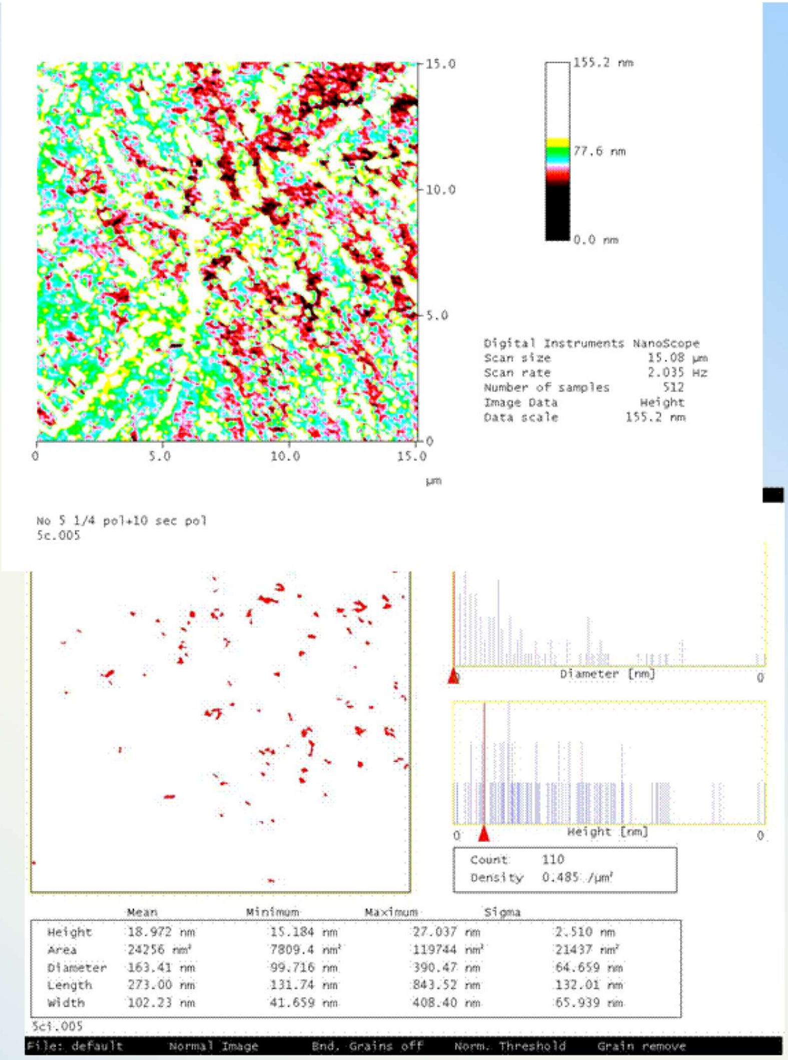
Creep specimen tested at 625C and interrupted at 18% of life

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

Bottom: Footprint of the cavities



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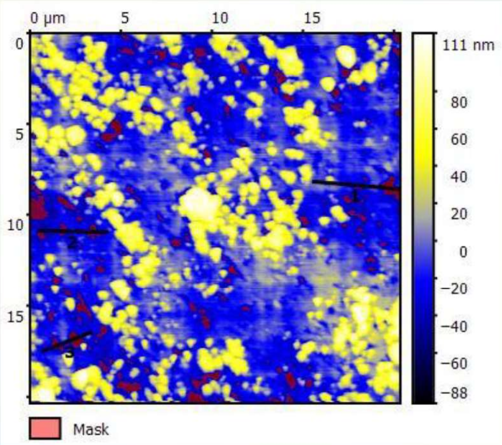

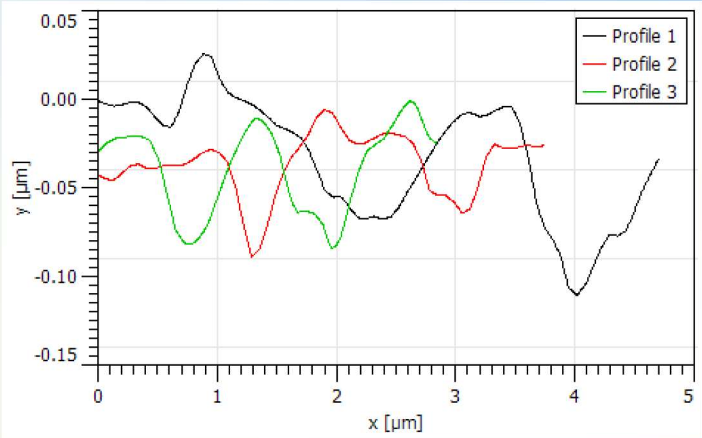

CAVITIES

Total projected area (abs.):	14.4 µm²
Total projected area (rel.):	3.48 %
Total cavities volume (zero):	0.82 µm³

PRECIPITATES

Total projected area (abs.):	61 µm²
Total projected area (rel.):	14.79 %
Total grain volume (zero):	3.7 µm³

SFM results for a Steam Pipe after a Service of 100kh at ~580C

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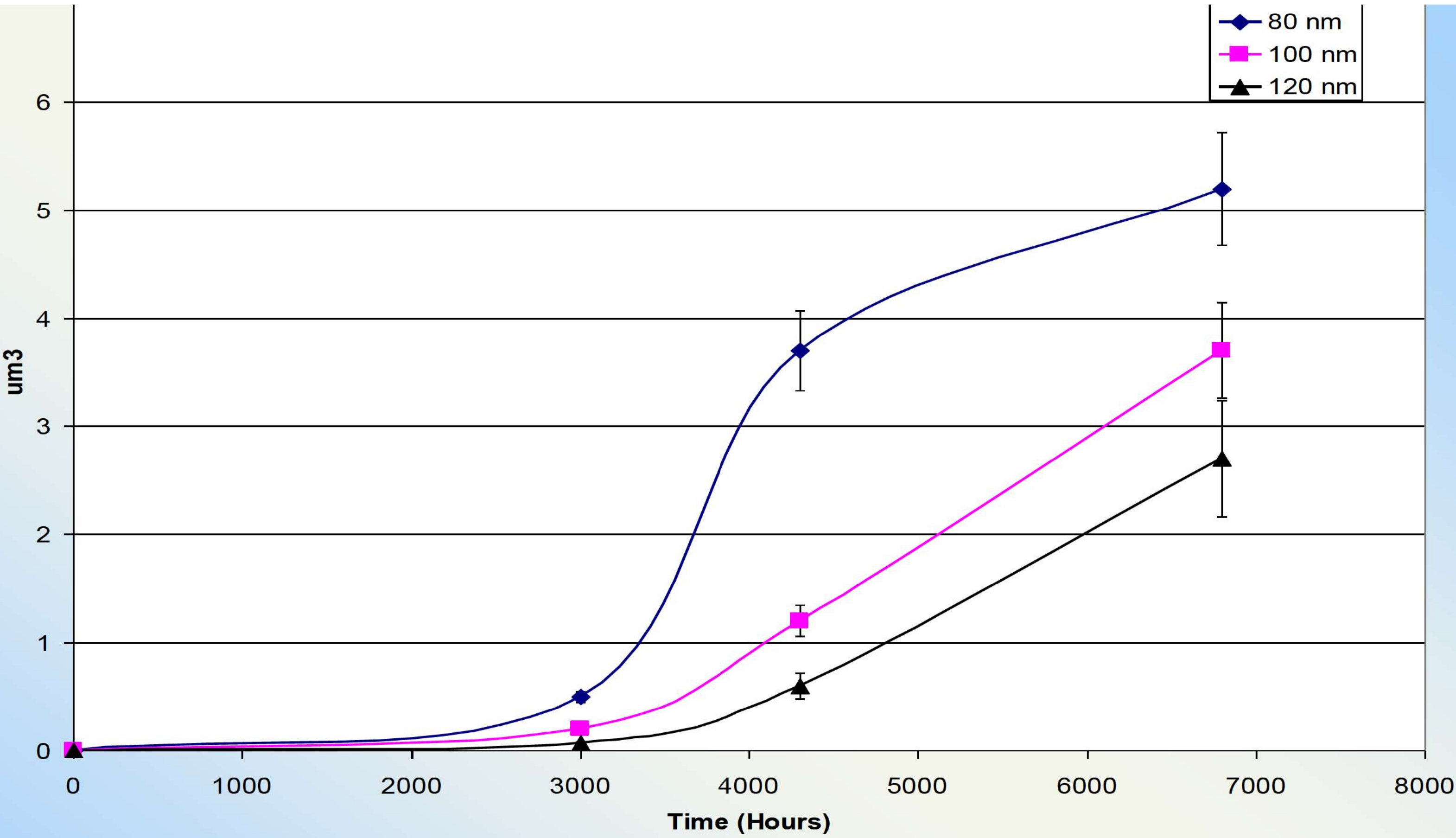

Volume of creep cavities (um3) in a 9Cr martensitic pressure vessel steel at 30%, 45% and ~70% of calculated service life of 10,000 hours

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Mounting Versatility

1st Stage of Rotor

2nd Stage of Rotor

Rotor Hot Section End

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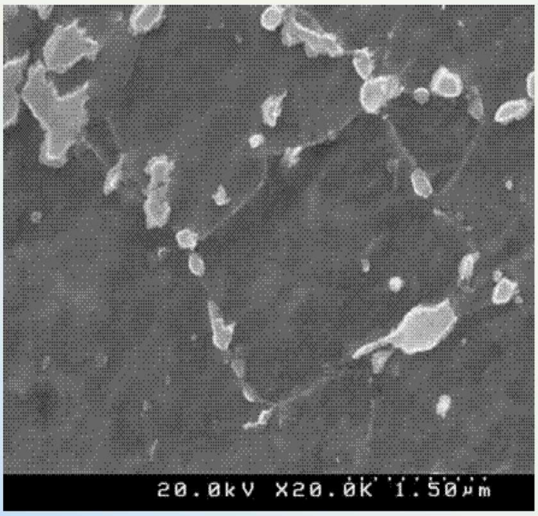
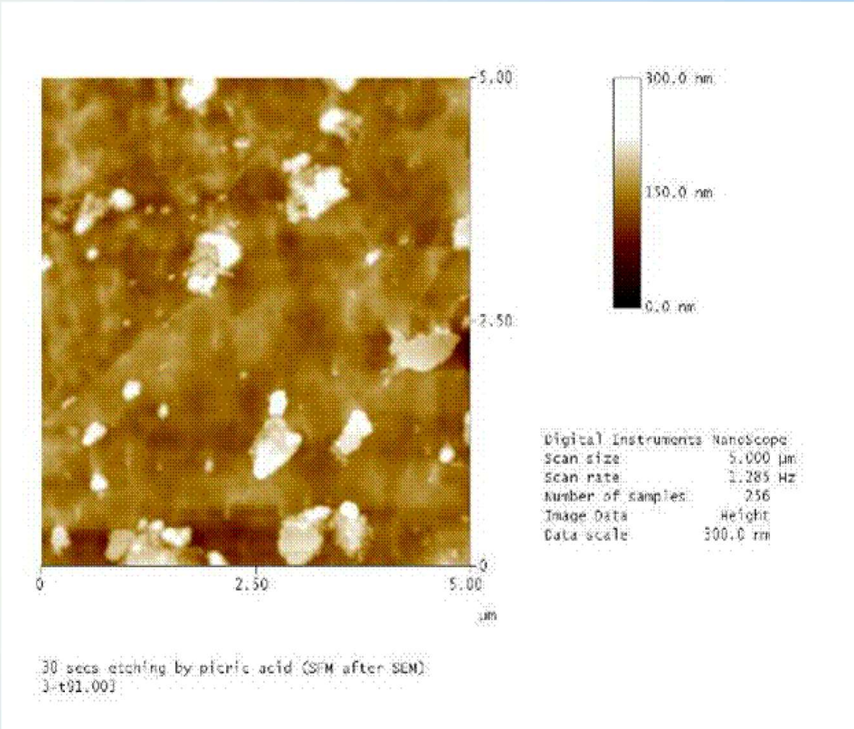
P91 after etching - SEM versus SFM





SEM

SFM –microstructural image in 3 dimensions

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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**

Cutting electrode

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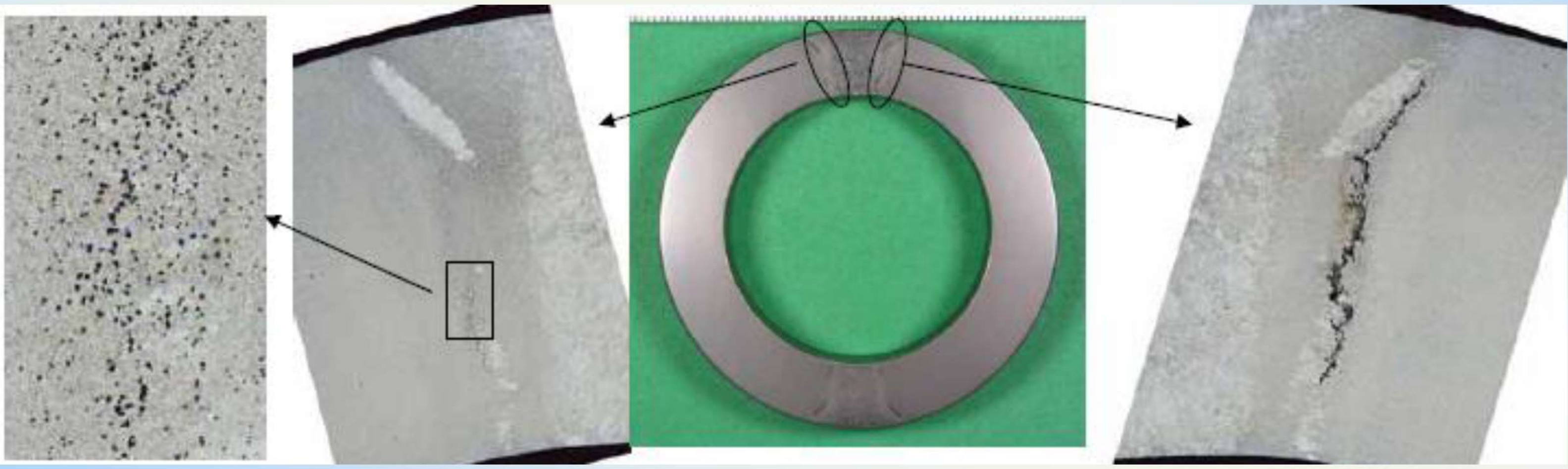
Type IV damage in seam-welded components

- Japanese study of creep cavitation damage accumulation at the Type IV position in a seam-welded T91 tube sample (of 10 mm wall thickness) under internal pressure



Ogata et al, Proc. "New Steels" Seminar, London, Sep 2008

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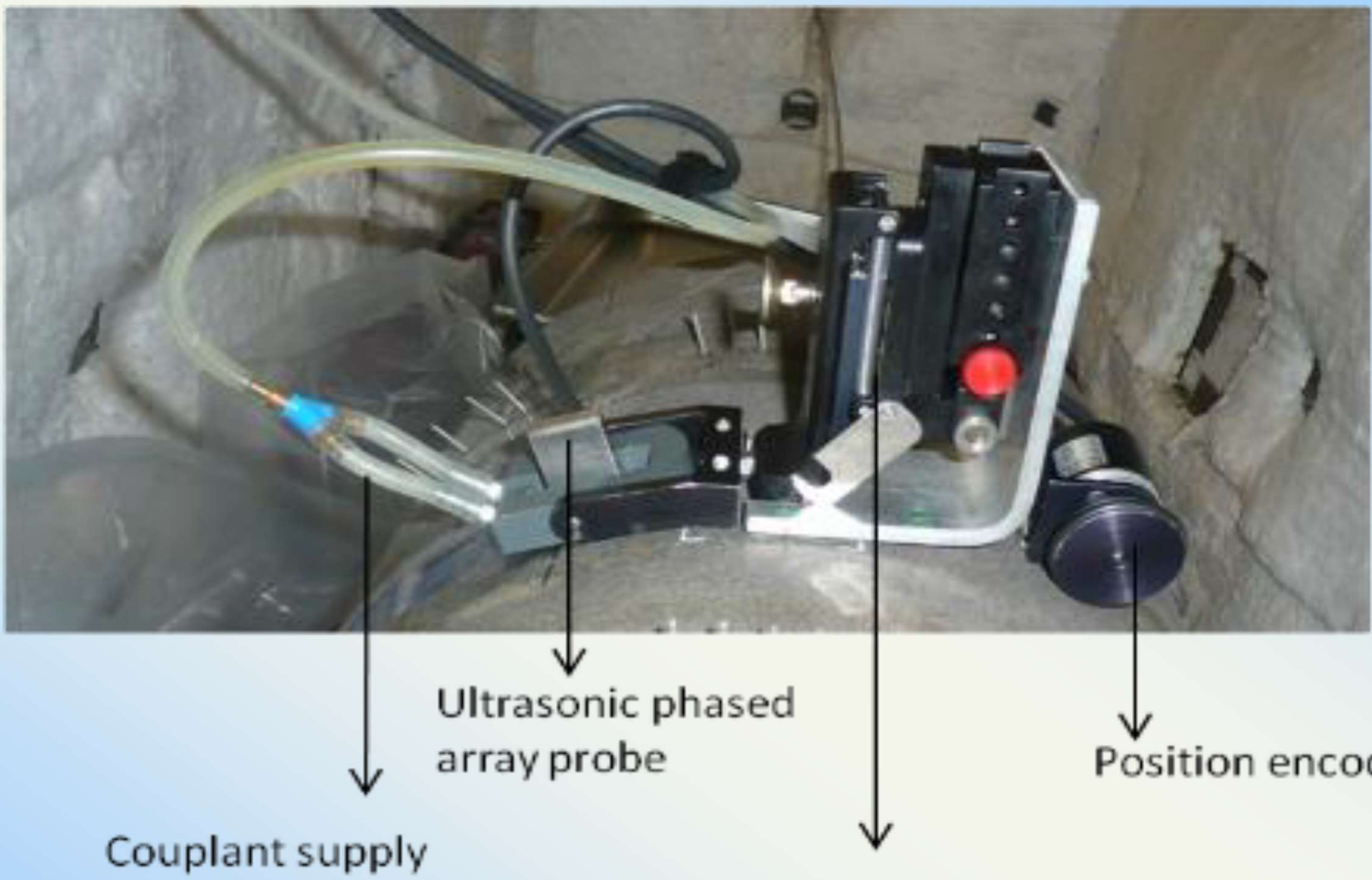

UT backscatter inspection tool *Ref: Engie*

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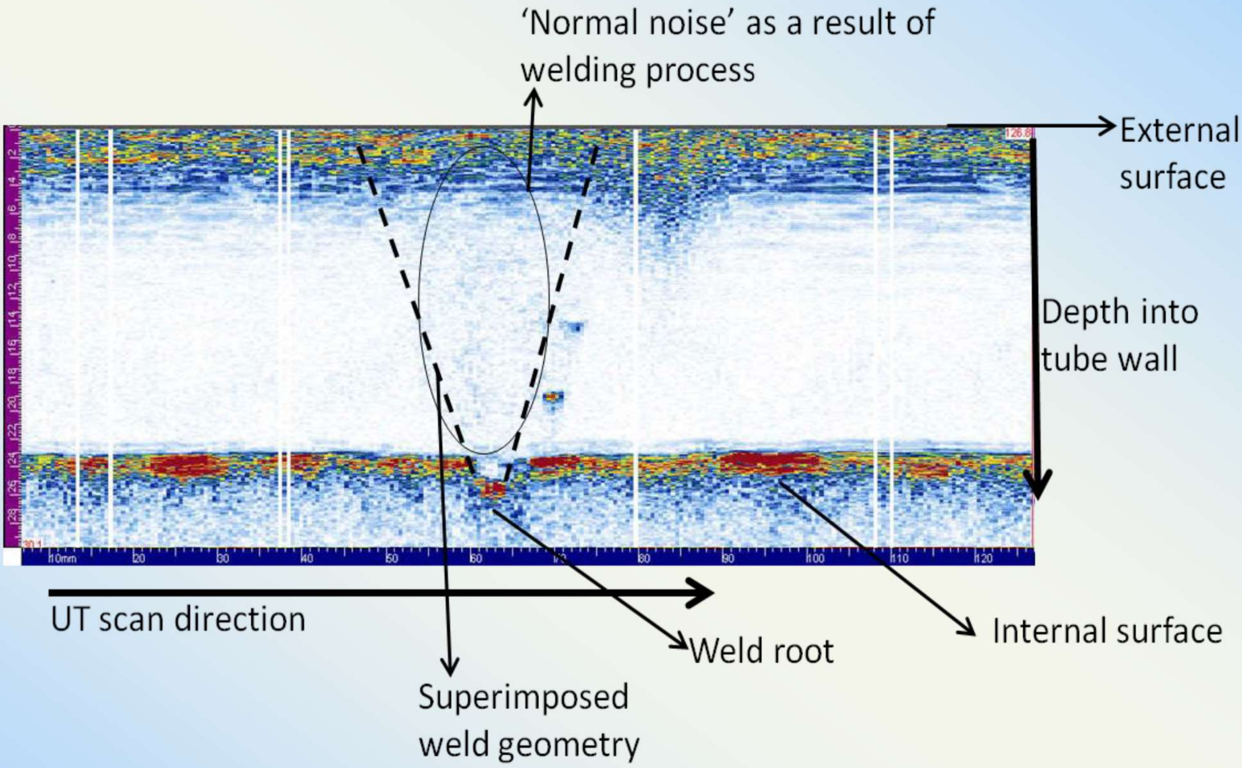

UT Back Scattering Method for Damage Detection and Quantification in a P91 welded pipe *(two spots on the right hand side of the weld show the early stage damage development – at 30% of the calculated life)*

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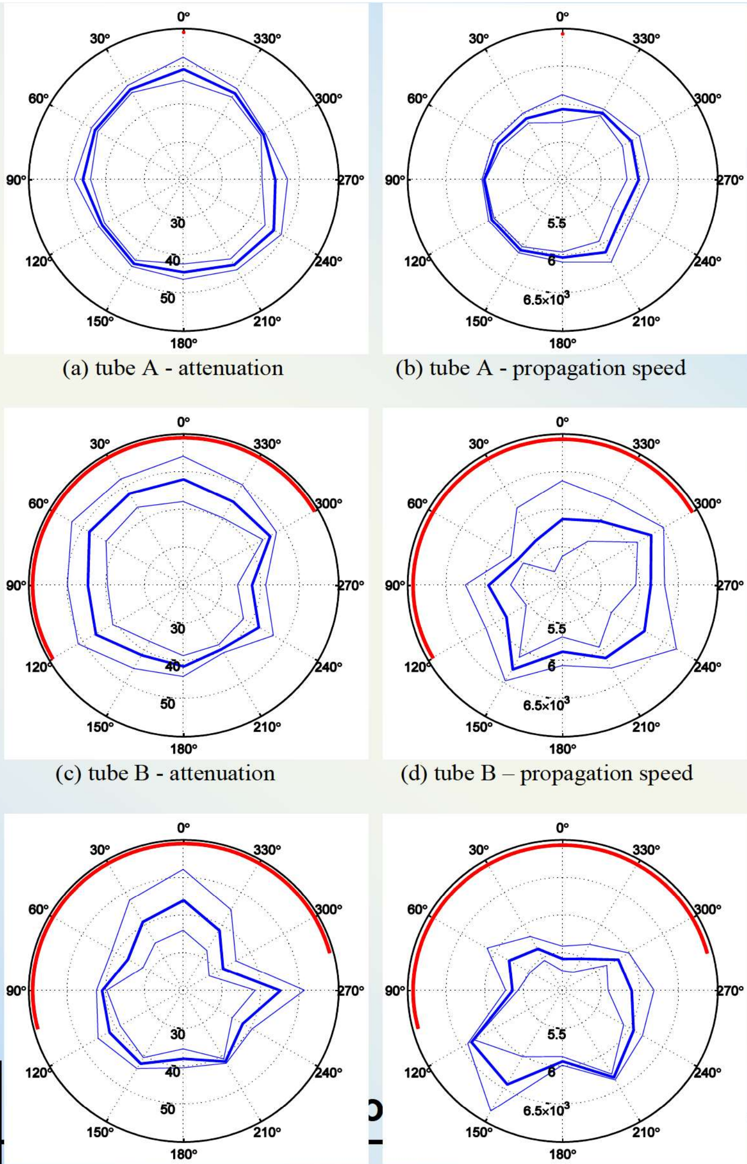
UT Velocity Ratio/Change Method



(a) tube A - attenuation

(b) tube A - propagation speed

(c) tube B - attenuation

(d) tube B – propagation speed

(e) tube C - attenuation

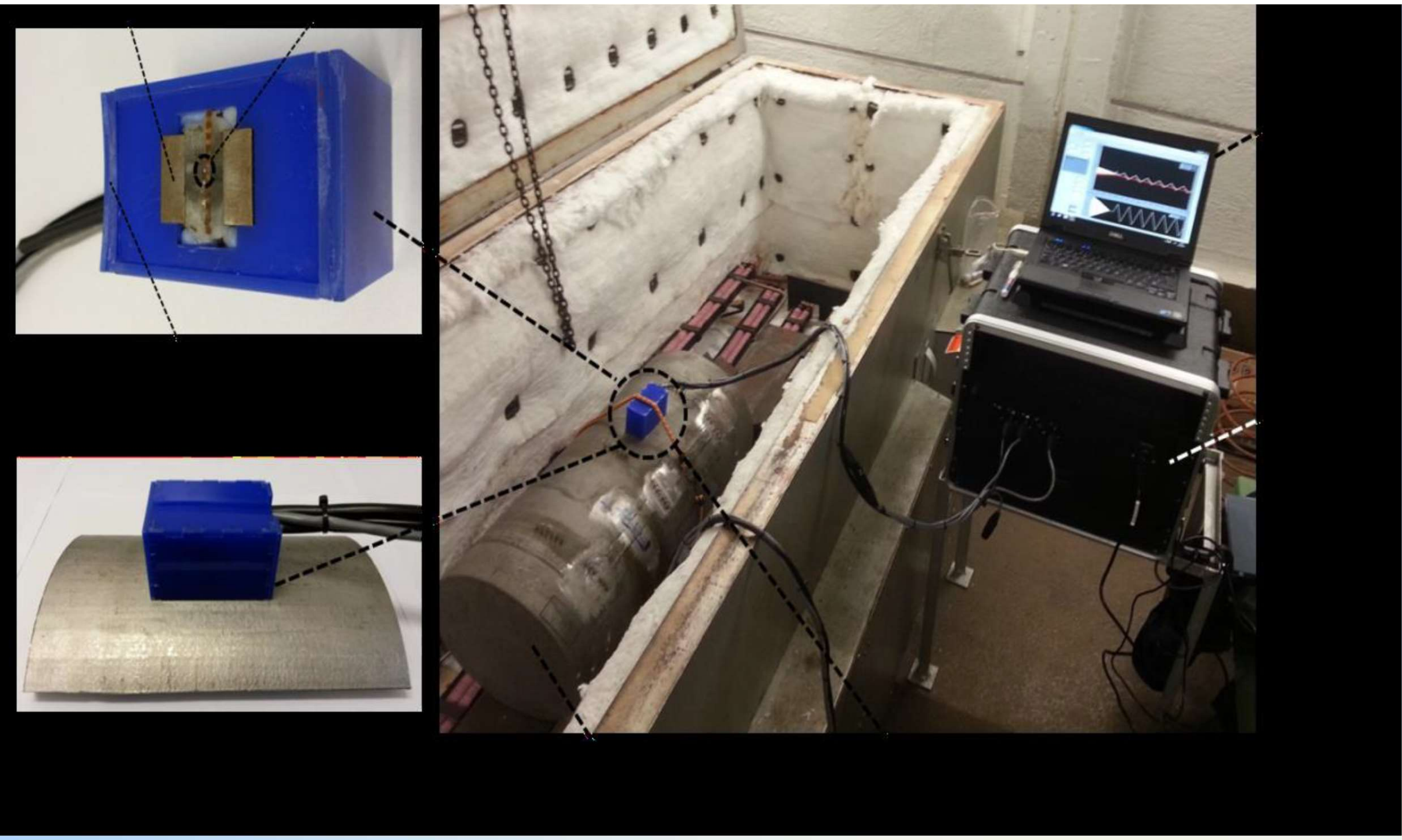
(f) tube C – propagation speed

Potential Drop Method- as a monitoring tool

Low frequency alternating current potential drop (LF-ACPD) method developed in the exploratory project showed the potential for monitoring the development of creep cavitation damage.

This requires systematic trials to confirm its validity in detecting and monitoring creep cavitation.

Work is also required to provide quantitative relationships between LF-ACPD measurements and creep life consumption.



Electromagnetic (EM) test system and probe design

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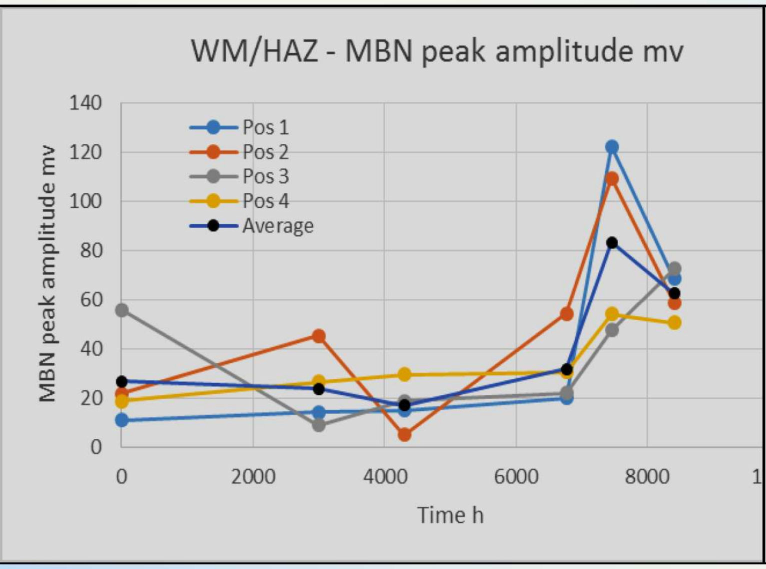

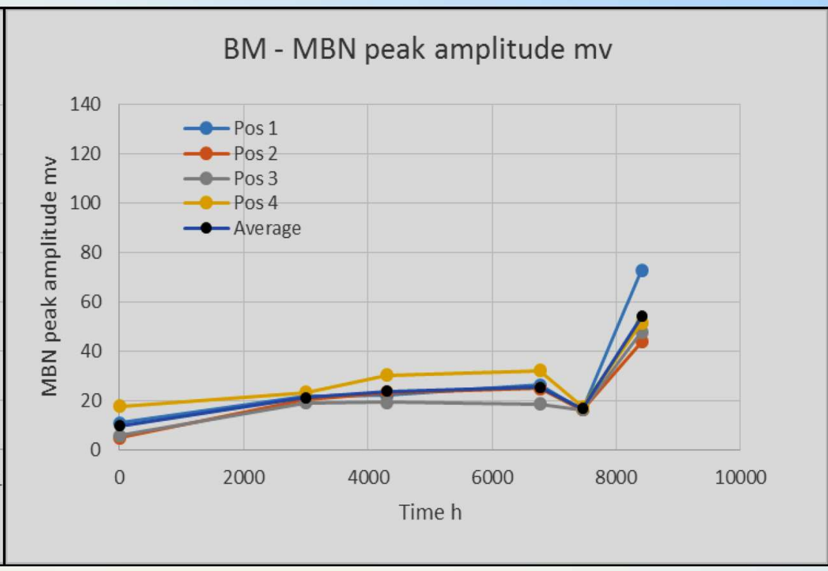

Magnetic Barkhausen Noise (MBN)

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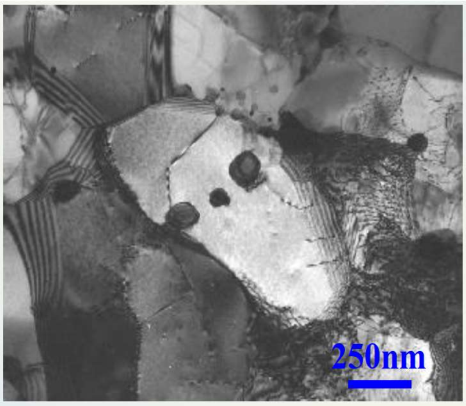
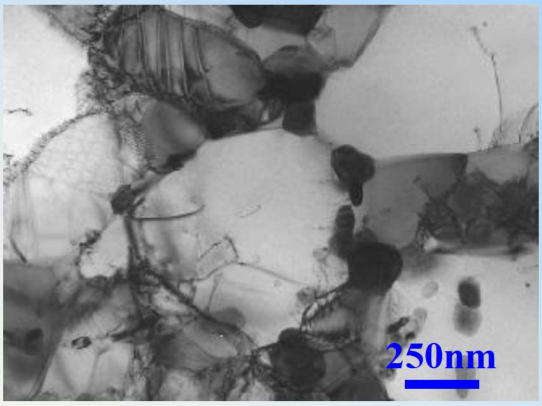
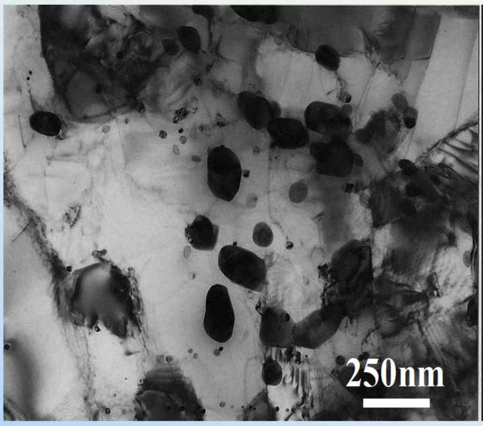


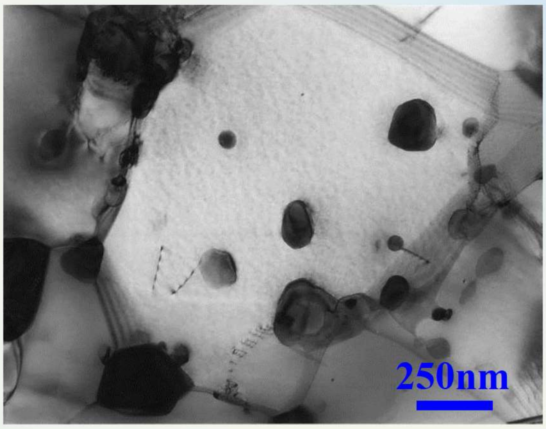
TEM image of FGHAZ- at initial state



TEM image of FGHAZ - EDSE at 2900h



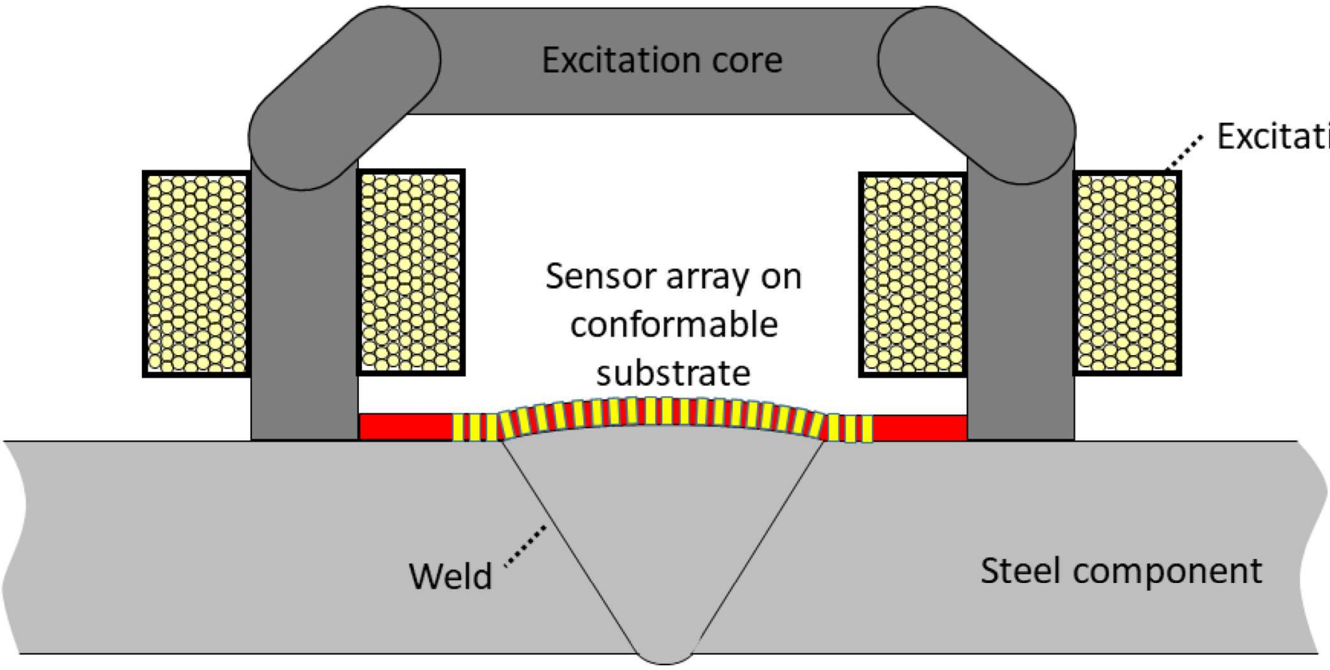
TEM image of FGHAZ - EDSE at 4300h



TEM image of FGHAZ- EDSE at 6800h

Change in grain boundary orientation as a new method for life assessment - *Nippon Steel & Sumitomo Metals*

Next GSPs: Improved version of EM Sensor



Proposed tool with sensor array for localised creep damage assessment

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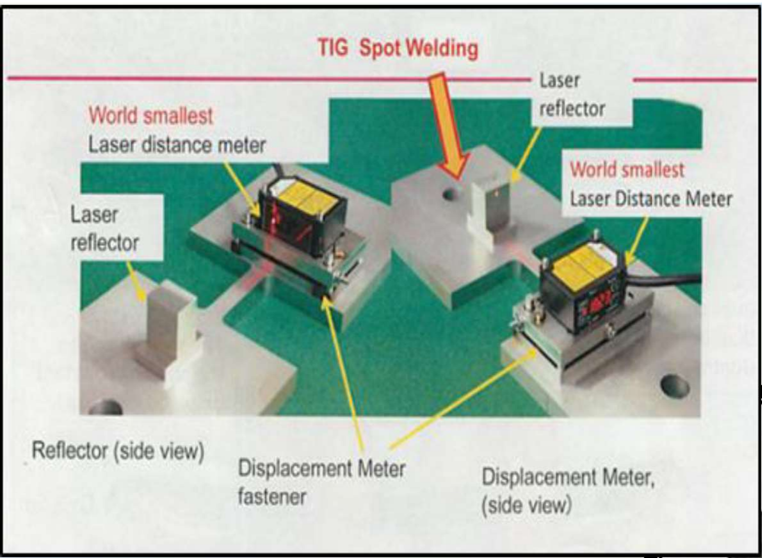

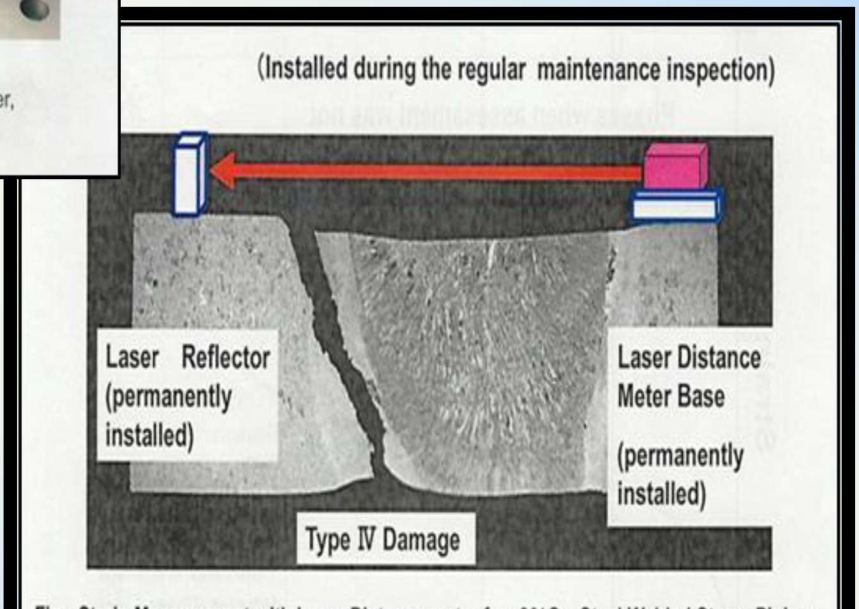

Fig. Strain Measurement with Laser Distance meter for 9%Cr Steel Welded Steam Piping

SMART SLEEVE: **New Portable Precision Hardness Tester**

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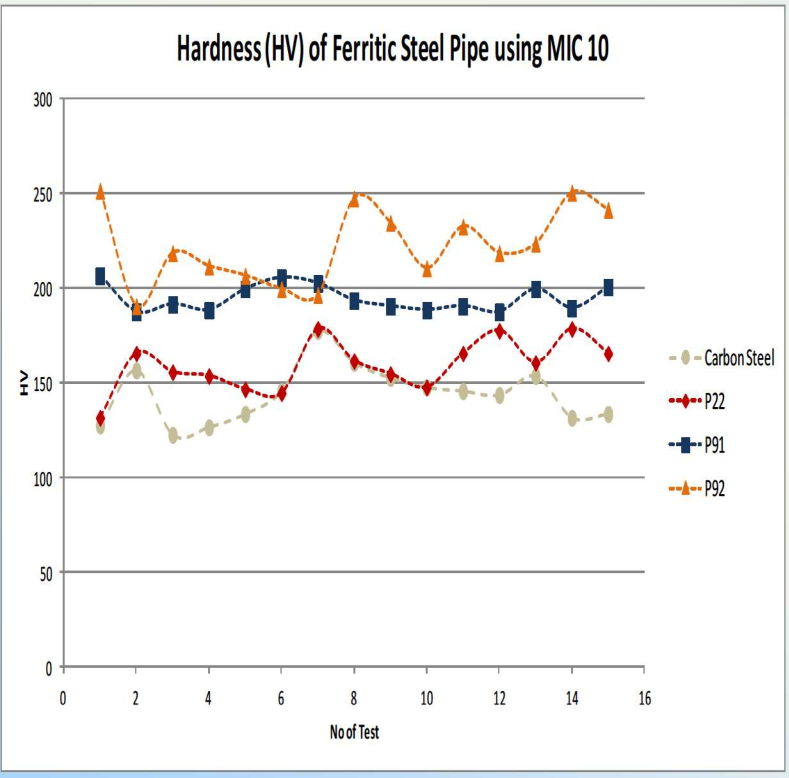
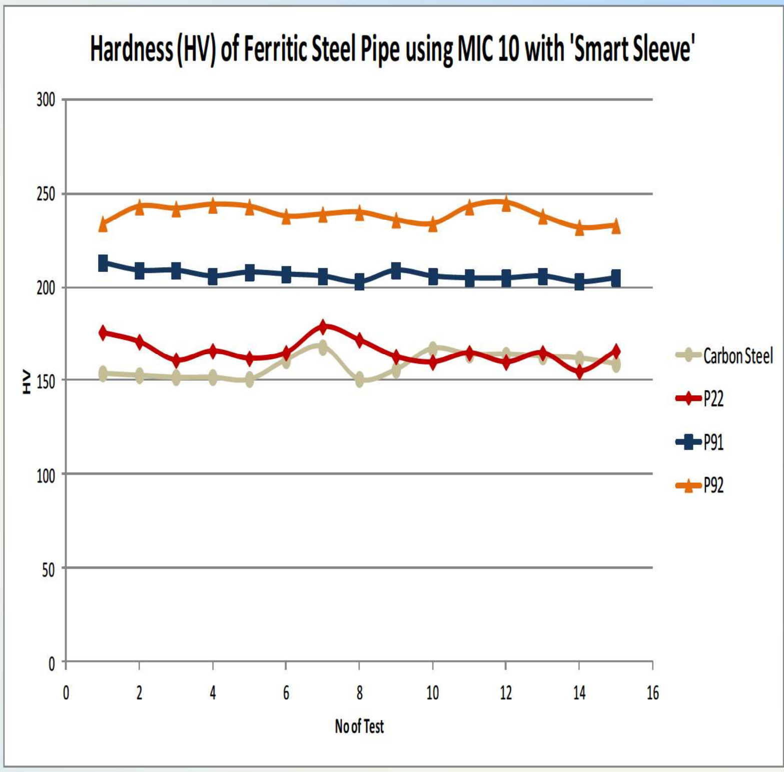
MIC10 hardness data with & without 'SMART SLEEVE'





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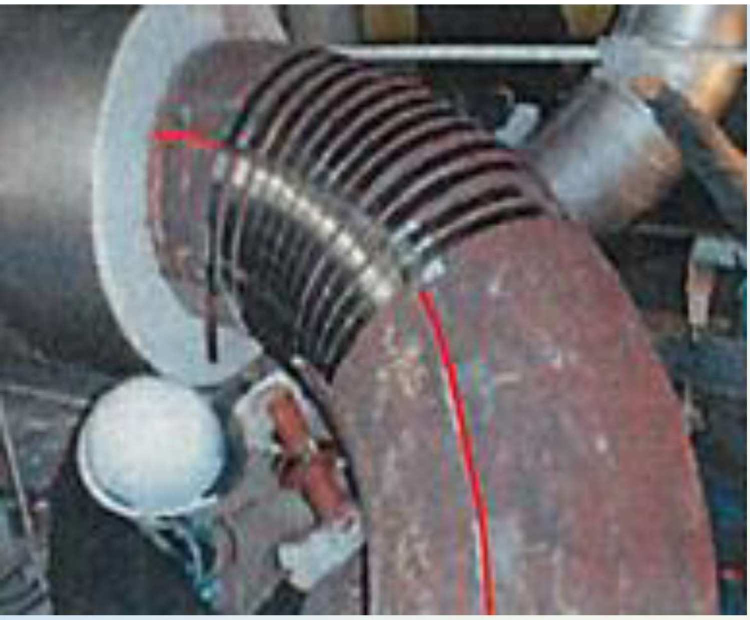

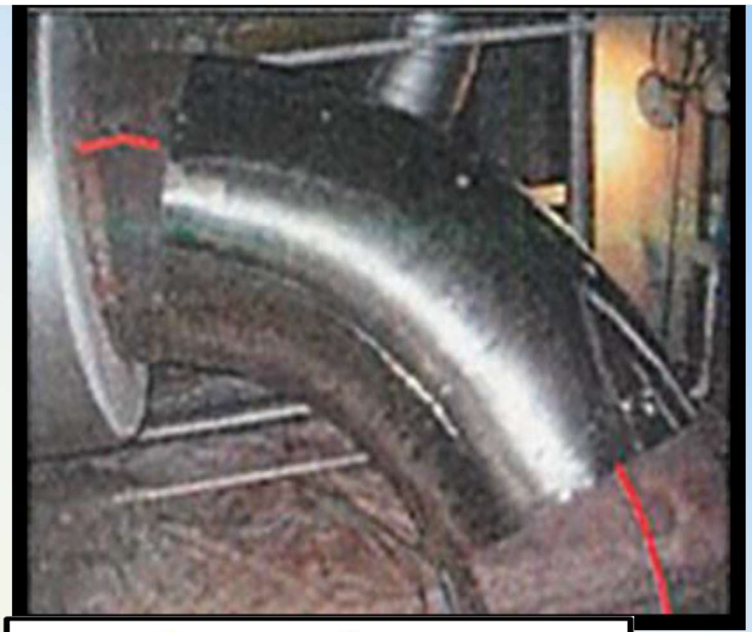

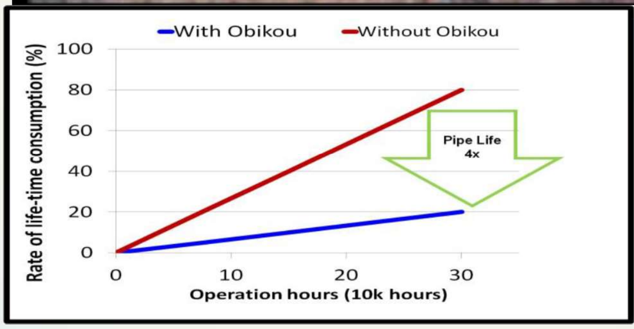

"Obikou" Reinforcement of components - life extension by x4

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A Bridge Between Industry and Research