Inspection and Life Assessment Challenges for the High Temp. Plant P91/P92 Components

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Problems with Integrity / Remaining Life Assessment in P91

- Observable cavitation by replicas does not show until late in life (~80% life).
- Traditional UT methods do not detect signs until about 70% of life.
- No spherodisation is observed (unlike low alloy steels).
Solution

• Scanning force Microscopy (SFM) can detect minor cavities of the size of a few nanometres and can thus help detect creep damage (or other damage in any material) early in life.

• The use of a portable SFM can make the use of replicas for on-site creep cavitation damage study a thing of the past.
Scanning Force Microscope. From top left hand (clockwise)- Lab version, original portable version, portable version hand held, portable version in use on a pipe ring.
Portable SFM being used on the creep damaged P91 welded pipe

Creep crack along pipe HAZ

Original/ older portable SFM being used on the creep damaged P91 welded pipe
Optical image of the pipe surface (in crack area) after mechanical polishing. Regions studies by SFM are shown as boxes.
SFM images acquired before and after chemical etching.

*Height data and depth distribution curves are shown at RHS*
High resolution SFM data including three-dimensional image
Conditions simulating industrial plant
(study of contribution of vibrations)

SFM can be sensitive to vibration

• Tests carried out using pipe and reheater tube samples.

• Three sets of experiments performed.
Regime 1: “Antivibration –ON”

Regime 2: “Antivibration-OFF”
(Studied in standard laboratory environment - contribution of acoustic noise & building vibrations).

Regime 3: “Antivibration –OFF + Additional Sources of Vibration”

A rotary pump switched ON very close to SFM (adding floor vibration) + vibrating vacuum tube from rotary pump placed close to SFM body.
SFM images in absence & presence of vibrations
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.
SFM and the laptop in a carry case
Aspects of Portable SFM Studied

1. SFM used to study cavitation in P91 creep specimens stopped at 20%, 30%, 40%, 50%, 70% and 90% of life.

2. Comparison of SFM images with replica images of cavitation and microstructure.

3. On-site use – on a Refining Plant in Italy on low alloy steel components.

4. On-site use- on a steam rotor in Poland
Cavity volume plot for the specimens tested at 600°C and 625°C
Dependence of the Cavities (Voids) volume concentration (in %) on t/t_r after treatment at 600C and 625C. 

$R^2 = 0.5932$

$R^2 = 0.8066$

Dependence of the Cavities (Voids) volume concentration (in %) on t/t_r after treatment at 600C and 625C.
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

SFM – microstructural image in 3 dimensions
SEM image of the replica of a creep damaged specimen
Replica image using SFM
Raffineria di Roma, Rome Italy, 18-19 May 2010

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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
A vertical pipe (Pipe 2) containing a circumferential weld polished and etched for SFM examination – low alloy steel operating at 565°C
SFM use on the vertical pipe
SFM use on the vertical pipe (Pipe 2). SFM head can be moved in two dimensions using the software and the laptop.
SFM images and results of the quantitative analysis for Pipe 1

Scan size 10 x 10 μm

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SFM testing of ‘Pipe 2’ HAZ
SFM Demonstration at Pro Novum Jaworzno, Poland
SFM analysis conducted on two steam rotors

Rotor 1

Rotor 2
Mounting Versatility

1st Stage of Rotor

2nd Stage of Rotor

Rotor Hot Section End
Rotor 1, location 1

Comparison of SFM & replication

Spheroidised carbides within the bainite and possible evidence of cavities

Presence of ferrite and bainite without any evidence of cavitation.

Spheroidised carbides and nano size cavities

Presence of ferrite and bainite without any evidence of cavitation.

(5% nital for 15 sec. etching)
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
Rotor 1, location 4

Replica findings

presence of ferrite and bainite with spheroidised carbides. No evidence of cavitation.

x100

presence of ferrite and bainite with spheroidised carbides. No evidence of cavitation.

x400
## Level of accuracy between standard replication and SFM characterisation technique

<table>
<thead>
<tr>
<th>Features</th>
<th>Standard Replication</th>
<th>SFM Characterisation</th>
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<tbody>
<tr>
<td>Microstructure (Ferrite and Bainite)</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Detection of early stage nano-size cavitation</td>
<td>Not possible</td>
<td>Very good</td>
</tr>
<tr>
<td>Carbide population and position</td>
<td>Medium</td>
<td>Good</td>
</tr>
<tr>
<td>Detection of spheroidisation (Nital 15sec.)</td>
<td>Medium</td>
<td>Very good</td>
</tr>
<tr>
<td>Detection of spheroidisation (Picric 90min.)</td>
<td>Good</td>
<td>Excellent</td>
</tr>
<tr>
<td>Detection of inclusions</td>
<td>Medium</td>
<td>Very good</td>
</tr>
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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

Other NDE Tools Developed Included:

a) Electrical Discharge Sampling Equipment (EDSE) for cutting out small flat pieces of metal for further examination / study.

b) Low Frequency AC Potential Drop Technique and Equipment for monitoring creep cavitation level damage in P91 and other steels.

c) High sensitivity ultrasonic ‘Velocity Change’ method for detection and grading of cavitation in high temperature components.
- Mechanism

**Copy System**

- Slide guide

Standard sample size:
5t x 25W x 30L

Sample thickness can be adjusted from 1mm to 5mm

Sampling takes only about 1.5 hours

**Well designed mounting**

Possible to mount horizontally and vertically

Possible to take samples axially and circumferentially

A. Axial  B. Circumferential

Sampling from various points on the object
Electrical Discharge Sampling Equipment in use on a P91 pipe
Utilization of Electric Discharge Sampling Equipment

Electric Discharge Sampling Equipment

Thin sample

Machining of small specimens

Implementation of various tests

- Tensile test
- Low-cycle fatigue test
- High-cycle fatigue test
- Creep test
- Relaxation test
- Small punch creep test
- Hardness test
- Microstructure analysis
- Microcomponent analysis
- Residual stress measurement

Residual life evaluation
Investigation of equipment damage
3. Material investigation of a gas turbine rotor (to check uniformity of forging and cast)

4. Failure investigation of welds inside piping (to compare with NDT)
   * including sampling from a pipe with an inside diameter of 1300 mm
Experimental setup for measurement of creep damage in tubes: (a) tube specimen A supported by fitted Perspex brackets, and (b) tube specimen B submerged in the water bath with the UT probe.
The thick and thin blue lines show the respective mean values and standard deviations of the measurements along the lengths of the tubes.
Thank You

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