QUARTERLY REPORT

Project WP#339: Structural Significance of Mechanical Damage

For Period Ending: August 31, 2008

Contract No: DTPH56-08-T-000011

Prepared For: United States Department of Transportation
Pipeline and Hazardous Materials Safety Administration
Office of Pipeline Safety

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ELECTRICORE

PRCI LEADING PIPELINE RESEARCH

Milestone and Deliverable Accomplishments this Reporting Period

Task No.	Task	Scheduled Completion Date	Completed Date	Milestone
1	Project Kick Off Meeting and Subcontracting	8/31/2008	8/31/2008	MS
2	Purchase & Characterize Pipe Material	11/30/2008	Ongoing	MS
3	Literature Review	11/30/2008	Ongoing	MS
4	Testing of Dents on Welds and Corrosion Features	11/30/2009	Ongoing	MS
5	Testing of Dents with Gouges	5/31/2010	Ongoing	MS
6	Demonstration of Mech. Damage Model Performance	5/31/2009	Not Yet Started	
7	Industry Workshop	5/31/2010	Not Yet Started	
8	Project Management and Reporting	5/31/2010	Ongoing	MS

Technical Status

Technical activities undertaken through the first quarter focused on the following tasks:

Task 2: Purchase & Characterize Pipe Material
Task 3: Literature Review
Task 4: Testing of Dents on Welds and Corrosion Features
Task 5: Testing of Dents with Gouges

A summary of the technical status and results or conclusions to date are presented below for each of these tasks.

Additionally, activities under Task 1 were completed this period. The project kick off meeting was held on July 11, 2008. Subcontracting has been completed between BMT Fleet and Gaz de France. Meeting notes from the July kick off meeting are presented as Appendix A.

Task 2: Purchase & Characterize Pipe Material

Technical Status

The entire program is comprised of evaluating the effects of mechanical damage defects on four different pipe steels called:

- Pipe 1
- Pipe 2
- Pipe 3
- Pipe 4

GDF SUEZ has received three pipes: Pipe 1 of 11.8 meters length and Pipe 2, including two pipes of the same material, with length of 11.8 meters. These pipe steels are current steels, one specified as API X52 grade and the second API X70 grade. The diameter of all pipes is 24’’ and the thicknesses are 7.9mm for the X52 grade (Pipe 1) and 9.0mm for the X70 grade (Pipe 2). The pipes are manufactured by IPSCO with ERW process.

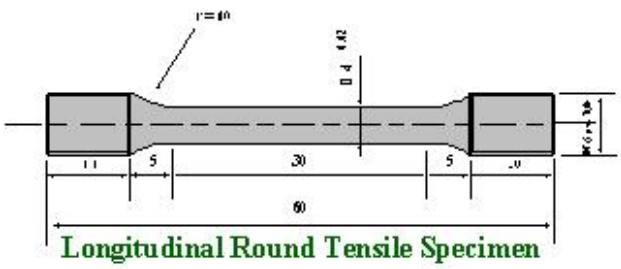
GDF SUEZ has investigated the following material's characterization on Pipe 1:

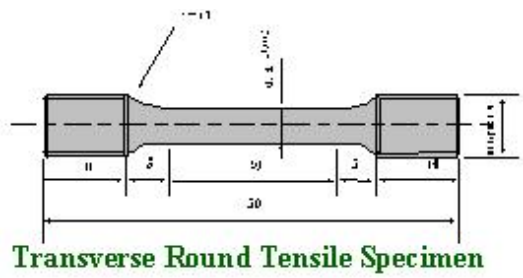
- Tensile properties;
- Impact Charpy values in different directions at room temperature;
- Toughness J Curve;
- Pre-strain effect on toughness J_{1C} at room temperature;

In addition, extra-work has been done to measure the size of slip bands of the material after deformation. This action has been taken to check the model described in a separate PRCI project (PRCI Project MD 4-3) linking the size of slip bands and the crack initiation during the dent creation.

Results and Conclusions

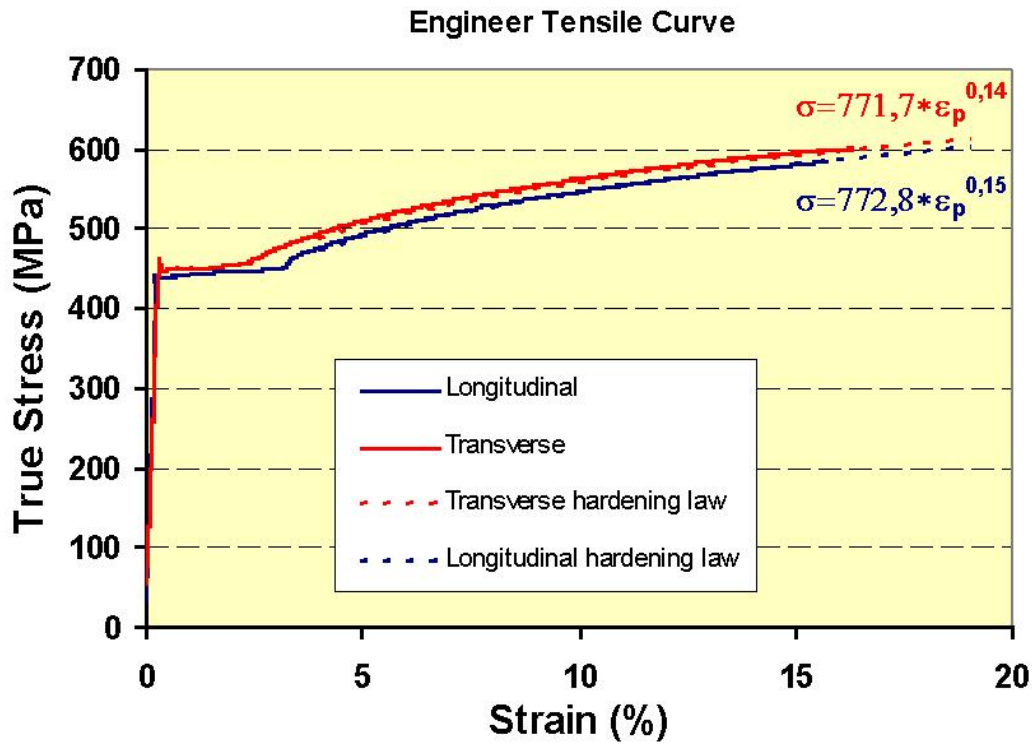
Tensile Properties at room temperature:



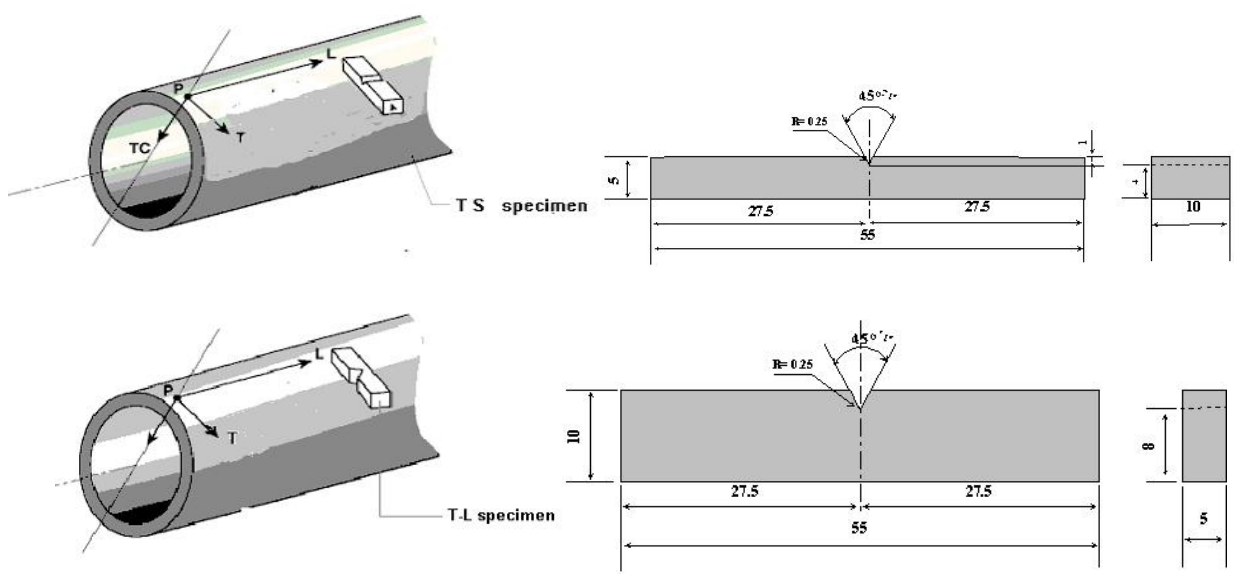


Tensile round bar specimens have been taken at 180° Clock position in the pipe.

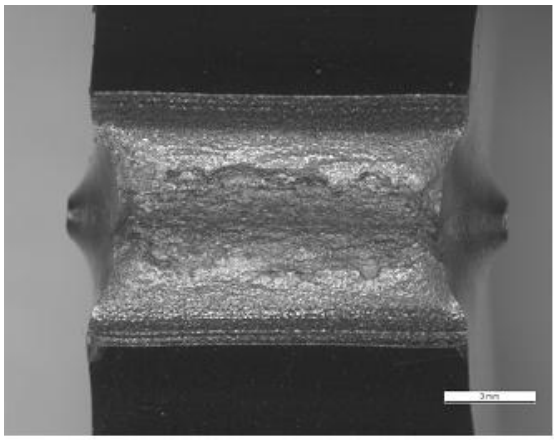
Pipe 1	YS (MPa)	UTS (MPa)	% Elongation
Transverse	448	512	31
Longitudinal	442	504	35



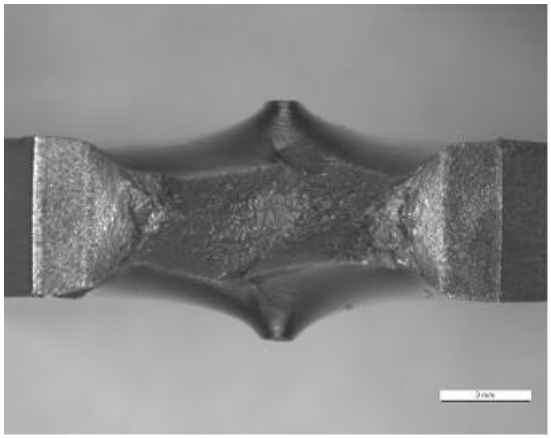
Impact Charpy values at room temperature:



Pipe 1	Impact Energy Value (J/cm²)	Rupture mode
TS	142	100% Ductile (no broken in two parts)
TL	234	100% Ductile (no broken in two parts)

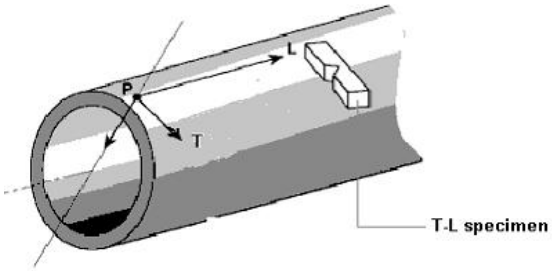


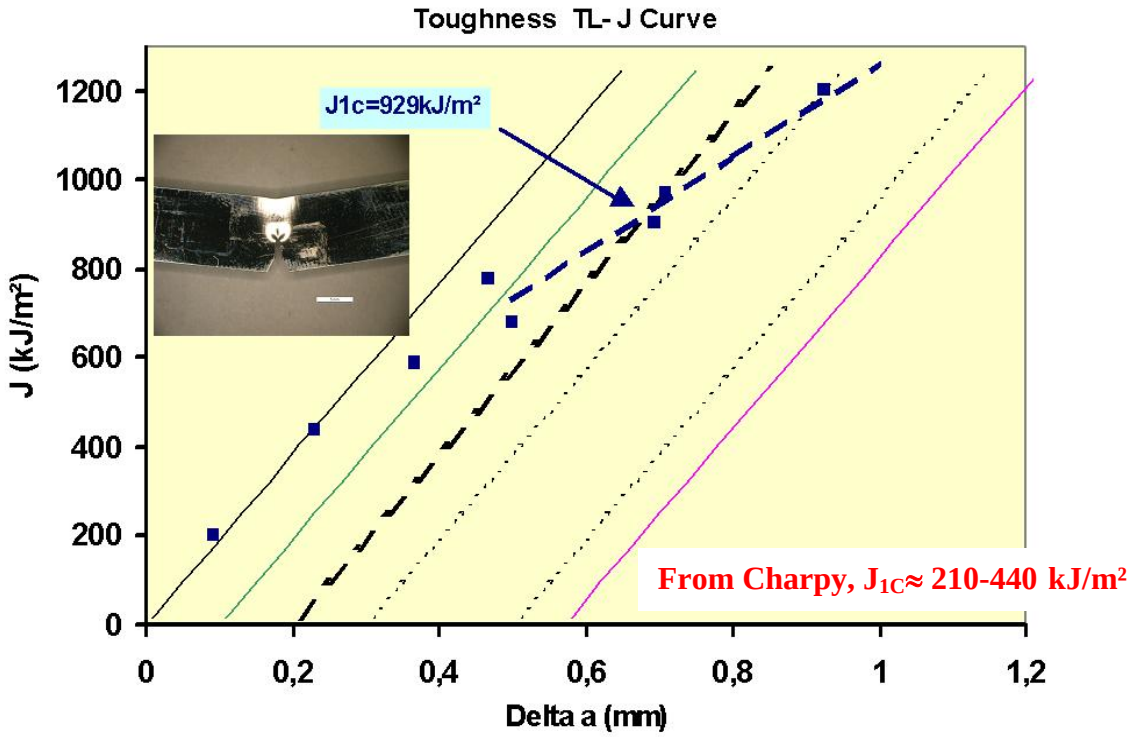
TS specimen facies

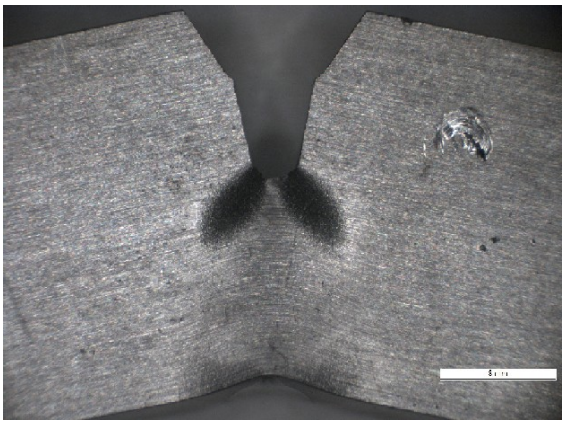


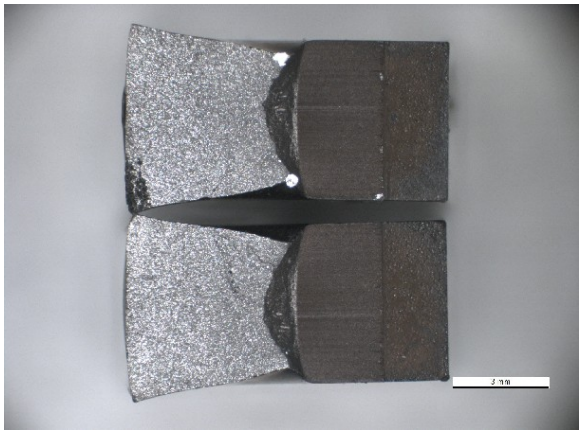
TL specimen facies

Toughness J-Curve at room temperature:



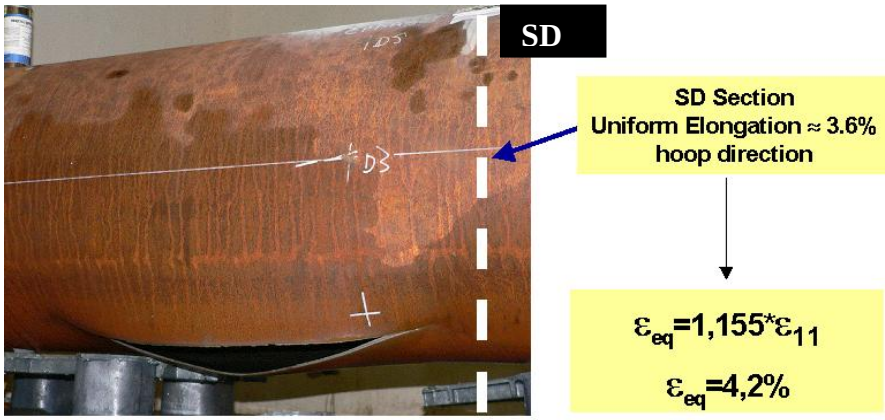


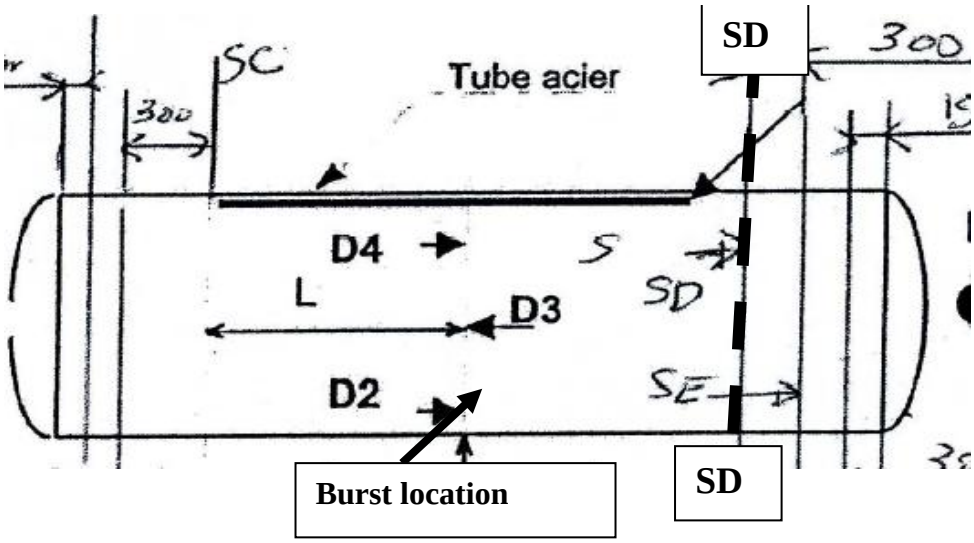




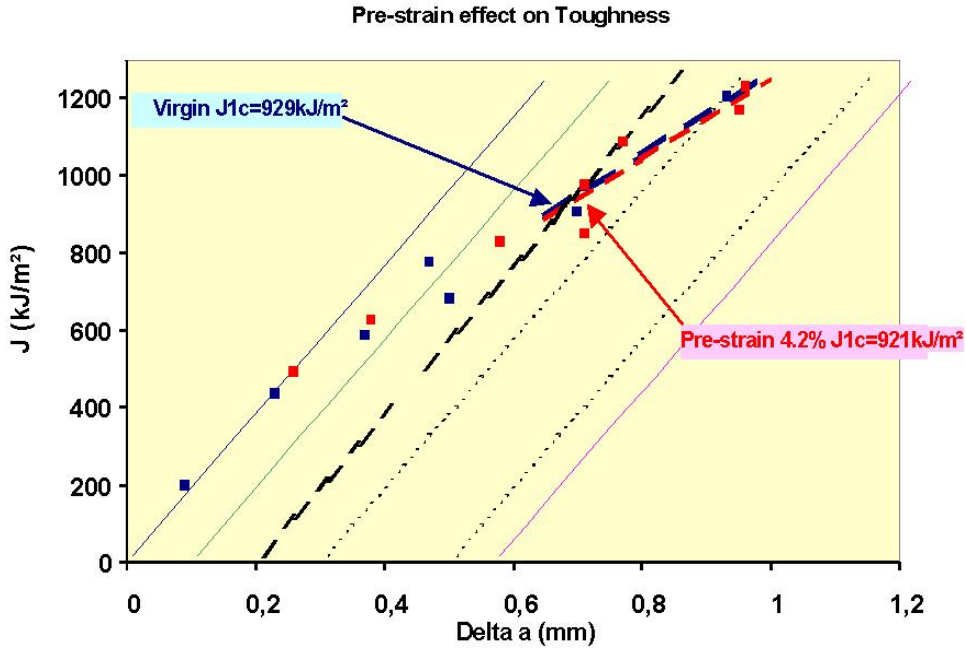
Pre-strain effect on Toughness J_{1C} at room temperature :

The pre-strain specimens have been taken in the SD section of the capacity containing the defect 1.1.2 after the burst test. Along the SD section, the strain due to the pressure at burst moment was about uniform and equal to 3.6% following the hoop direction. In terms of equivalent strain that means 4.2%.



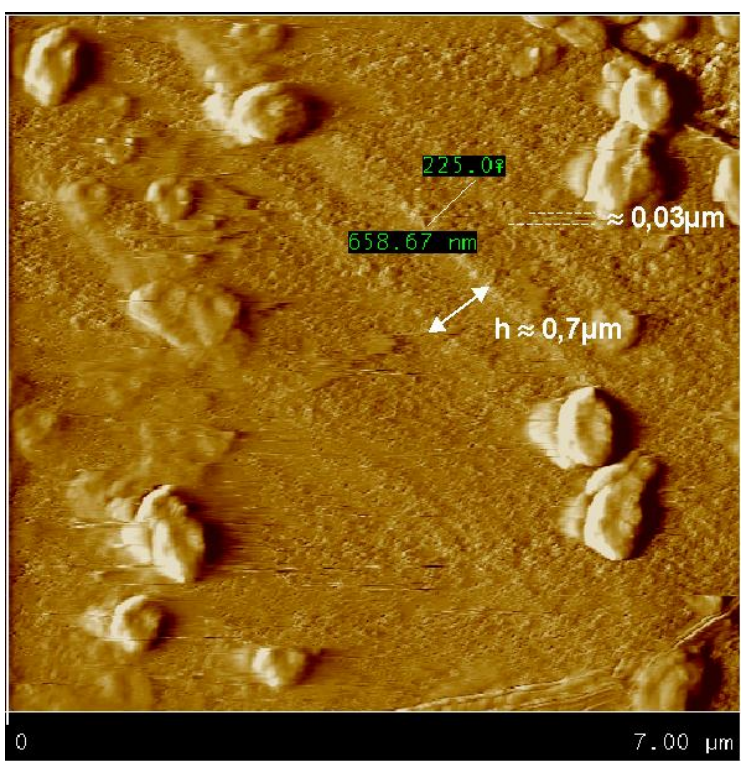


The specimen configuration was TL with the same geometry described in the previous paragraph.



Extra-work – Measurement of Size of Slip-bands:

A strip tensile specimen has been loaded up with a strain equal 3.5% to create slip-bands. Using AFM (Atomic force Microscope) the slip-band width and height have been measured.



For 3.5% strain the slip-band width and height are respectively equal to 0.7µm and 0.03µm.

Procurement of Additional Pipe Material

A source of manufacturing new pipe replicating the observed lower toughness of 1950's or 60' linepipe has not been identified to date. US Steel, IPSCO, British Steel, Berg, and four pipe storehouses have been contacted. These leads and others are being followed up.

A survey to PRCI members requesting vintage pipe steels has been distributed as a back-up plan in the event that the new low toughness steel procurement fails.

The delay in procuring the additional steel will not have a negative impact on the overall project schedule until the fourth quarter of the project. Due to the difficulties in procuring the steel, completion of this task will be delayed from 6 to 12 months. If the procurement has any additional delay or begins to impact the overall project schedule, the team will request a modification to the project milestone schedule with revised plan to complete the project.

Main Conclusions – 31 August 2008:

- Actual tensile properties of Pipe 1 material, specified as API X52 grade, are close to API X65 grade;
- Pipe 1 is a very ductile material with a high toughness value;
- 4% of pre-strain has no effect on the high toughness of the Pipe 1 material;
- For a 3.5% of pre-strain the slip-band width and height are respectively equal to 0.7µm and 0.03µm

Task 3: Literature Review

Technical Status

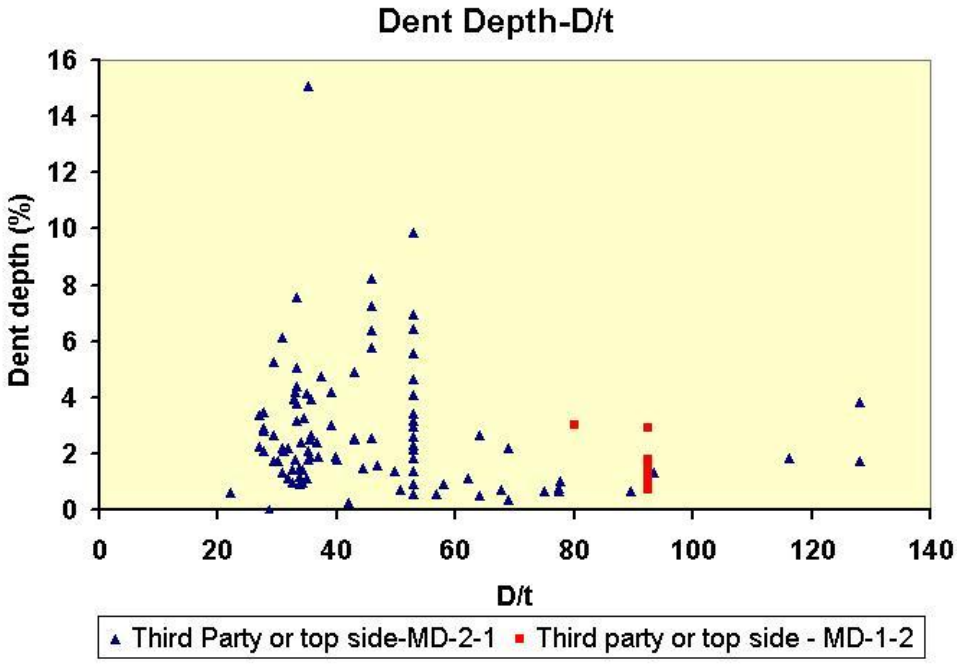
The Literature Review has been led on two matters by GDF SUEZ:

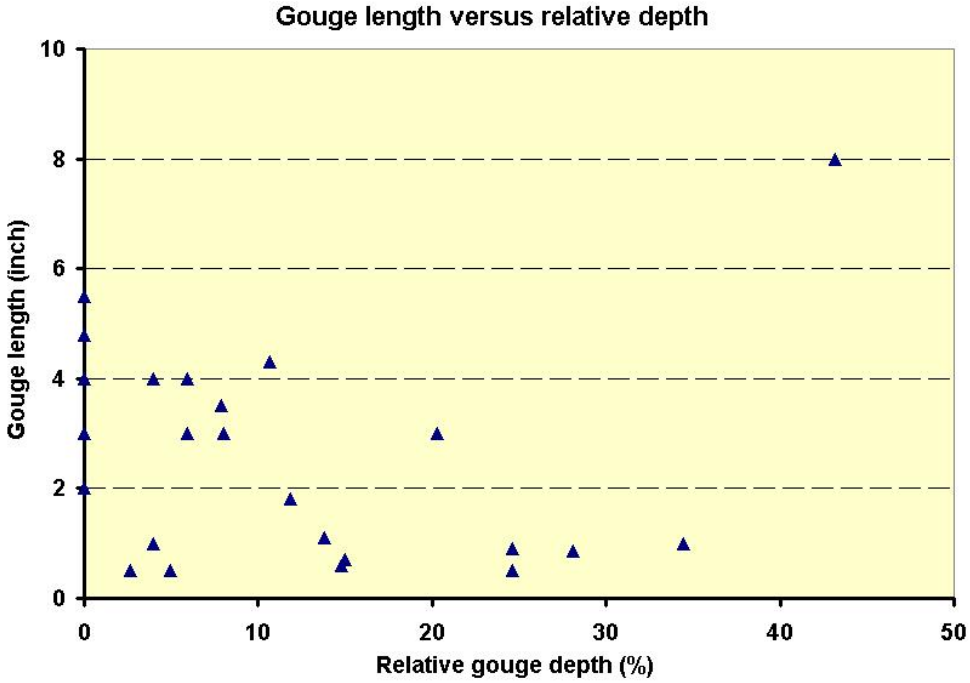
- Investigation on the geometry of realistic defects such as dent, gouge, gouges in dent on field
- Pre-strain effect on toughness.

Results and Conclusions

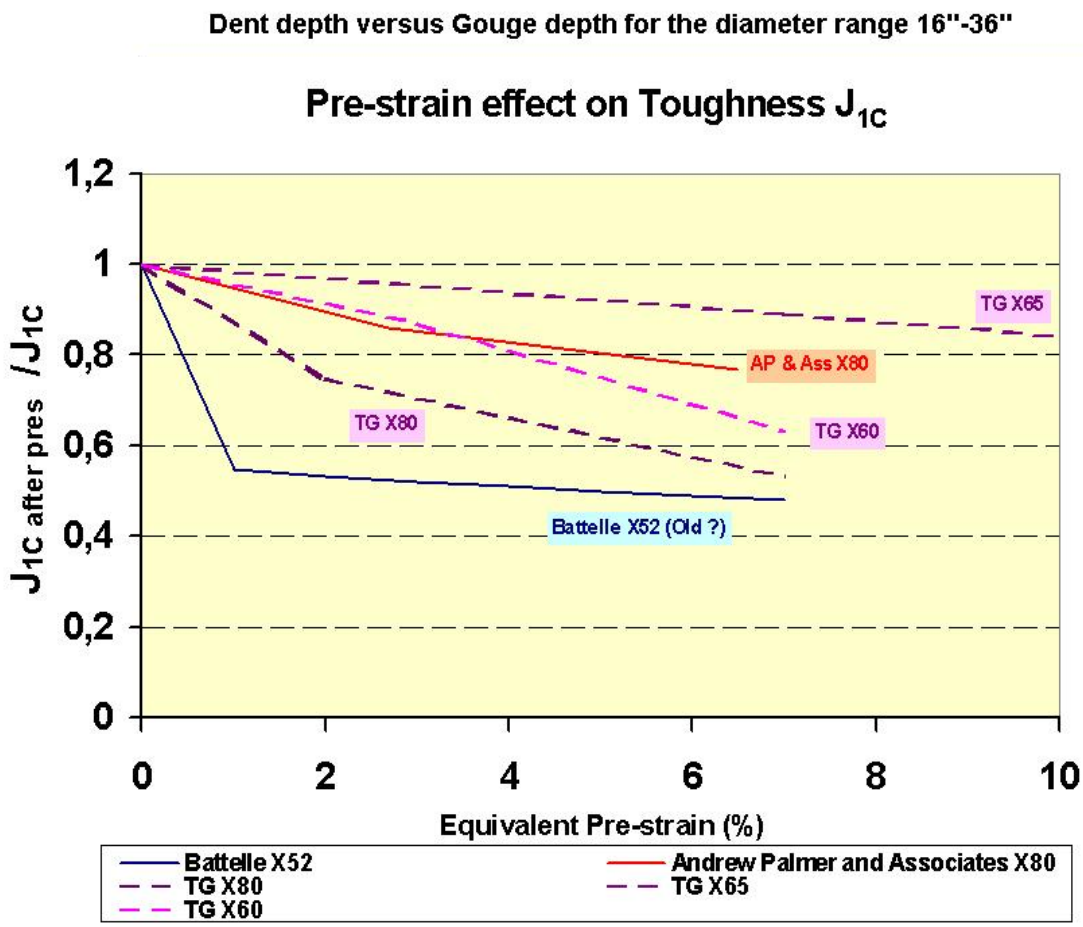
Investigation on the geometry of realistic defects such as dent, gouge, gouges in dent on field:

Recent PRCI projects called MD-1-2 and MD-2-1 have been interpreted to provide a statistical view of the geometric parameters of realistic defects.


Dent Depth-D/t
Dent depth (%)
D/t
Third Party or top side-MD-2-1
Third party or top side - MD-1-2


Gouge length versus relative depth
Gouge length (inch)
Relative gouge depth (%)

Pre-strain effect on toughness:



Several results of different studies from Battelle, Tokyo Gas and Andrew Palmer and Associates have been gathered to exhibit the trend of pre-strain effect on material's toughness.

Main Conclusions – 31 August 2008:

The first investigation on data from field inspections gave the following results:

- For D/t ratio above 60, the dent depths are below 4% from statistical analysis of the field data. The D/t ratio>60 is in accord with high pipeline diameter which have a thicker wall and relatively small pipeline diameters;
- The gouge depths can reach to 40 % but the large number of cases are below 20%;
- When the gouge length decreases, the relative depth of gouge increases;
- The trend shows when the relative gouge depth diminishes, the dent depth increases.

The analyses of the literature do not show a general law of the decreasing of toughness versus the pre-strain, even if the same trend of toughness decreasing is observed for all materials. The reality is more complex and the ductility level of the material could influence the rate of toughness decreasing versus the pre-strain.

Task 4: Testing of Dents on Welds and Corrosion Features

Technical Status

The testing procedure, measurements and measurement systems/equipment, reporting and schedule details have been clarified and documented to allow testing to begin. The testing process will make use of a new higher capacity water pump purchased for this project and will increase the rate of testing in the program.

Results and Conclusions

Testing will commence in the next quarter with the first six test specimens being instrumented to capture the dent strain responses.

Task 5: Testing of Dents with Gouges

Technical Status

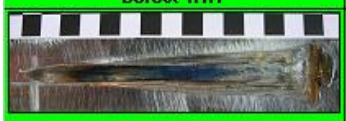
GDF SUEZ is managing the creation, characterization, burst test and fatigue test of realistic combined defects "gouge in dent" following the program described in the next table:

PR 305, pipe 1 & pipe 2	MD 4-1					MD 4-6		DOT	
Pipe number	**Pipe 1** (current steel X52)			**Pipe 2** (current steel)		**Pipe 3** (older steel)		**Pipe 4** (older steel)	
Defect type agreed with Project team	Type 1	Type 2	Type 3	Type 1 or 2	Type 2 or 3	Type 1 or 2	Type 2 or 3	Type 1 or 2	Type 2 or 3
Defect 1: Detailed characterization	Defect 1.1.1	Defect 1.2.1	Defect 1.3.1	Defect 2.1.1	Defect 2.2.1	Defect 3.1.1	Defect 3.2.1	Defect 4.1.1	Defect 4.2.1
Defect 2: Burst test	Defect 1.1.2	Defect 1.2.2	Defect 1.3.2	Defect 2.1.2	Defect 2.2.2	Defect 3.1.2	Defect 3.2.2	Defect 4.1.2	Defect 4.2.2
Defect 3: Delayed failure	Defect 1.1.3	Defect 1.2.3	Defect 1.3.3	Defect 2.1.3	Defect 2.2.3	Defect 3.1.3	Defect 3.2.3	Defect 4.1.3	Defect 4.2.3

The defects are identified by three characters **x.y.z.** which are numbers:

- **x**.y.z. : **x** identifies the **Pipe x** material (i.e., Pipe 1, 2, 3 or 4);
- x.**y**.z. : **y** defines the type of combined defect characterized by its geometry notably in terms of dent depth and length and gouge depth and length. In this program, the value of y can be in the range of 1 to 3, as this program considers a maximum of three different kind of defects per pipe material;
- x.y.**z.** : **z** is the number designating the individual sample for each of the types of defects created, y. There are three similar test specimens/samples created per type of defect. Sample number 1 is for a detailed geometrical, mechanical and metallurgical characterisation to fully understand the defect and its effect on pipeline properties after its creation. Sample number 2 is a similar defect for the burst test to know the behavior of defect under the monotonic pressure load, and sample number 3 is an identical defect for the fatigue test to know the defect behavior under variation of internal pressure.

Defects 1.1.1, 1.1.2, 1.1.3, 1.2.1, and 2.1.1 have been created by GSF SUEZ and are shown in the table below.

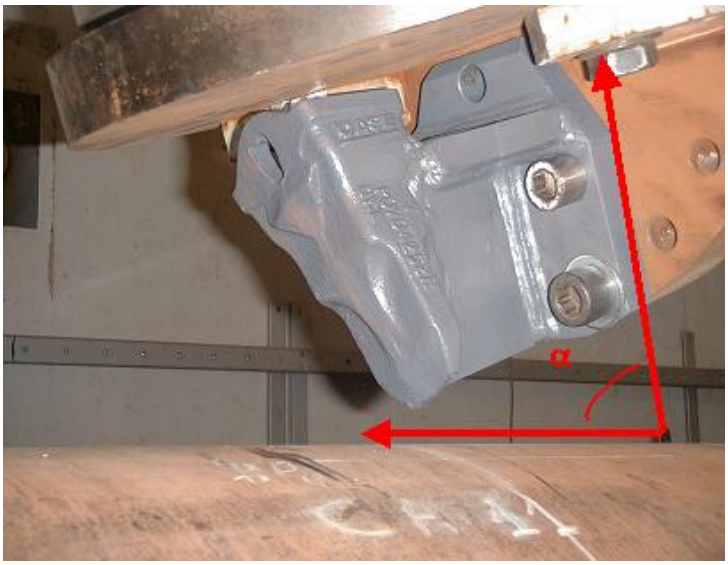
MD 4-1				
Pipe 1 (current steel X52)			**Pipe 2** (current steel)	
Type 1	**Type 2**	**Type 3**	**Type 1 or 2**	**Type 2 or 3**
Defect 1.1.1	**Defect 1.2.1**	*Defect 1.3.1*	**Defect 2.1.1**	*Defect 2.2.1*
 **Defect 1.1.2**	Defect 1.2.2	*Defect 1.3.2*	Defect 2.1.2	*Defect 2.2.2*
Defect 1.1.3	*Defect 1.2.3*	*Defect 1.3.3*	*Defect 2.1.3*	*Defect 2.2.3*

This information that follows presents the results of testing and analyses completed on these defects.

Results and Conclusions

Creation of defects

The defects are created by GDF SUEZ using their Pipe Aggression Rig, or PAR. The parameters to create the defects are defined by the aggressor tooth type and geometry, the height of the tooth before the fall, the additional masses, and the impact angle α of tooth with the pipe.



Defects 1.1.1, 1.1.2, 1.1.3

Tooth type	Impact angle α (°)	Drop Height (mm)	Additional Mass (Kg)	Internal Pressure (bar)
Cal44New	81	170	0	85

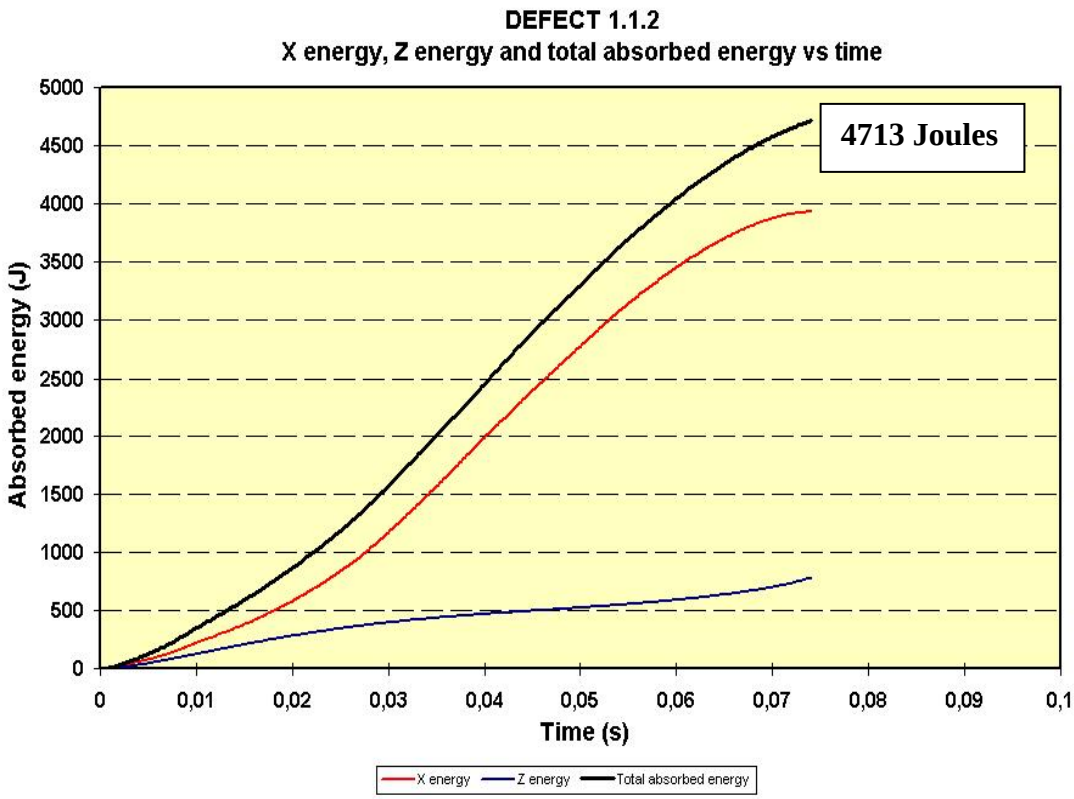
Defect 1.2.1

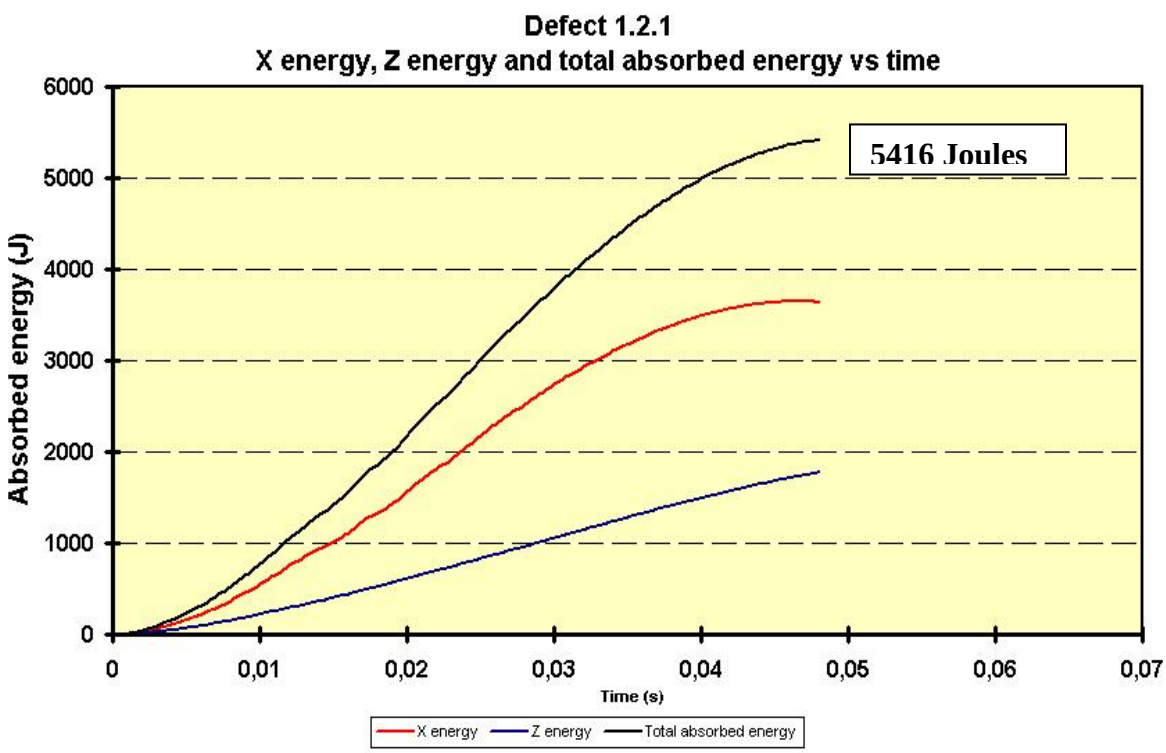
Tooth type	Impact angle α (°)	Drop Height (mm)	Additional Mass (Kg)	Internal Pressure (bar)
Esco	76	270	800	85

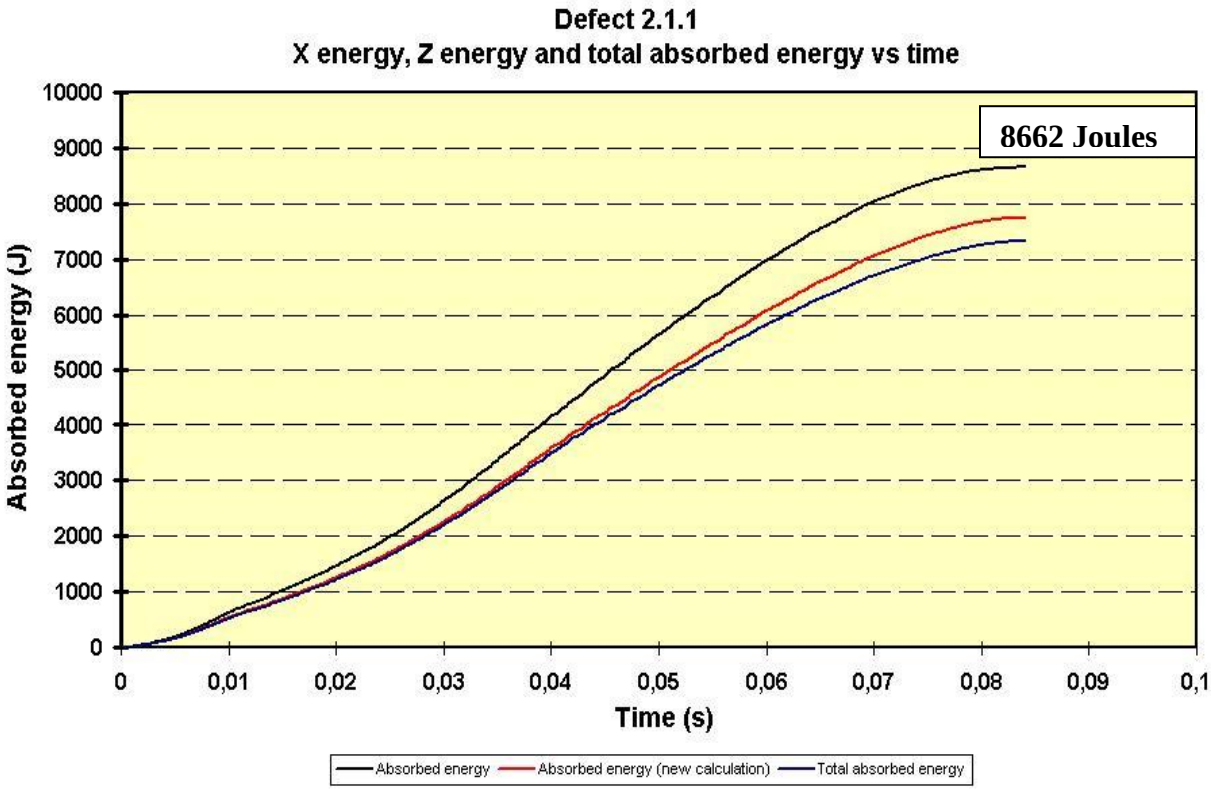
Defect 2.1.1

Tooth type	Impact angle α (°)	Drop Height (mm)	Additional Mass (Kg)	Internal Pressure (bar)
Esco	81	170	800	85

Energy absorbed by the creation of defects

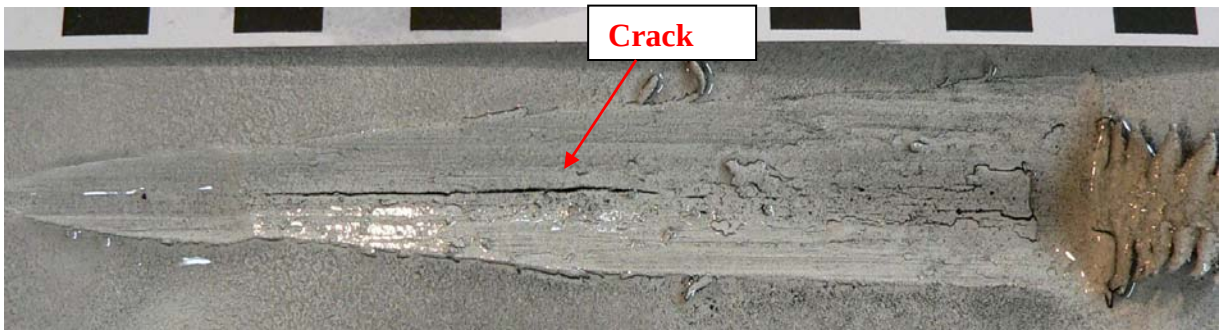




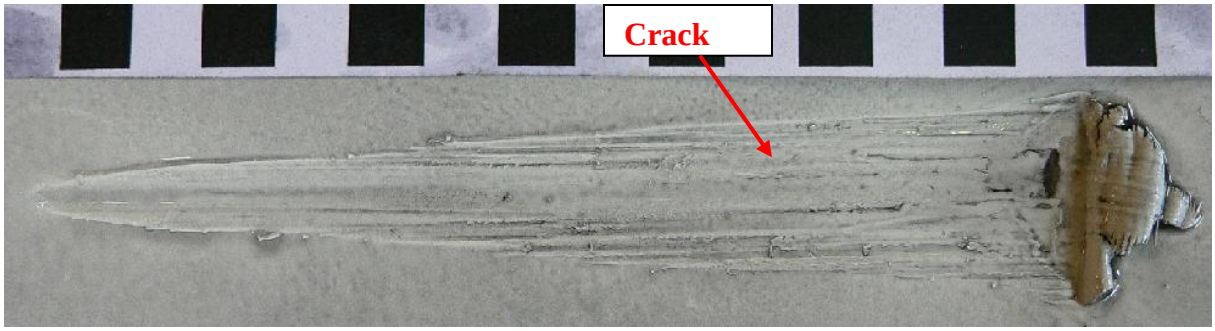


Detection of micro-cracks in gouge surface

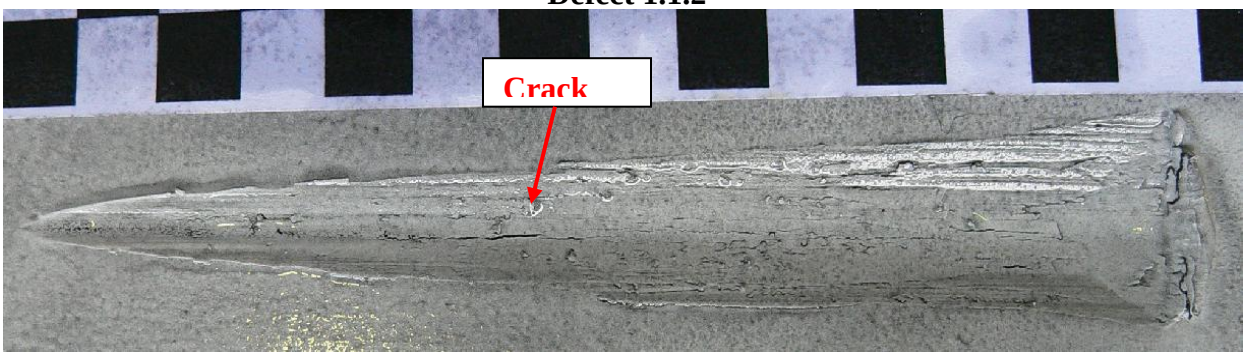
After the defect creation, magnetic powder tests have been applied to identify potential surface micro-cracks in the gouge.



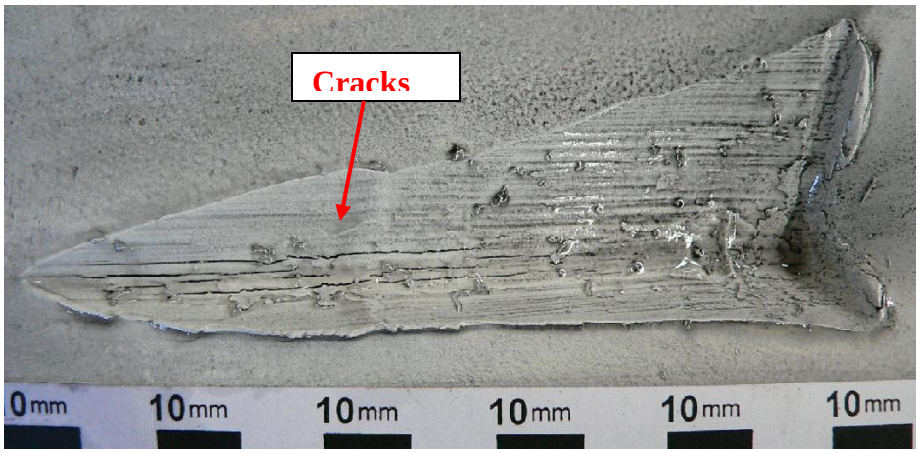
Defect 1.1.1



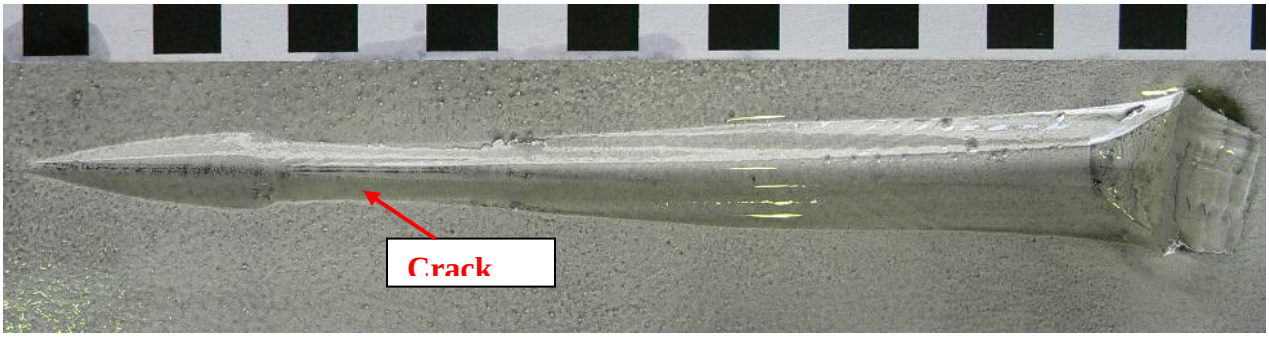
Defect 1.1.2



Defect 1.1.3



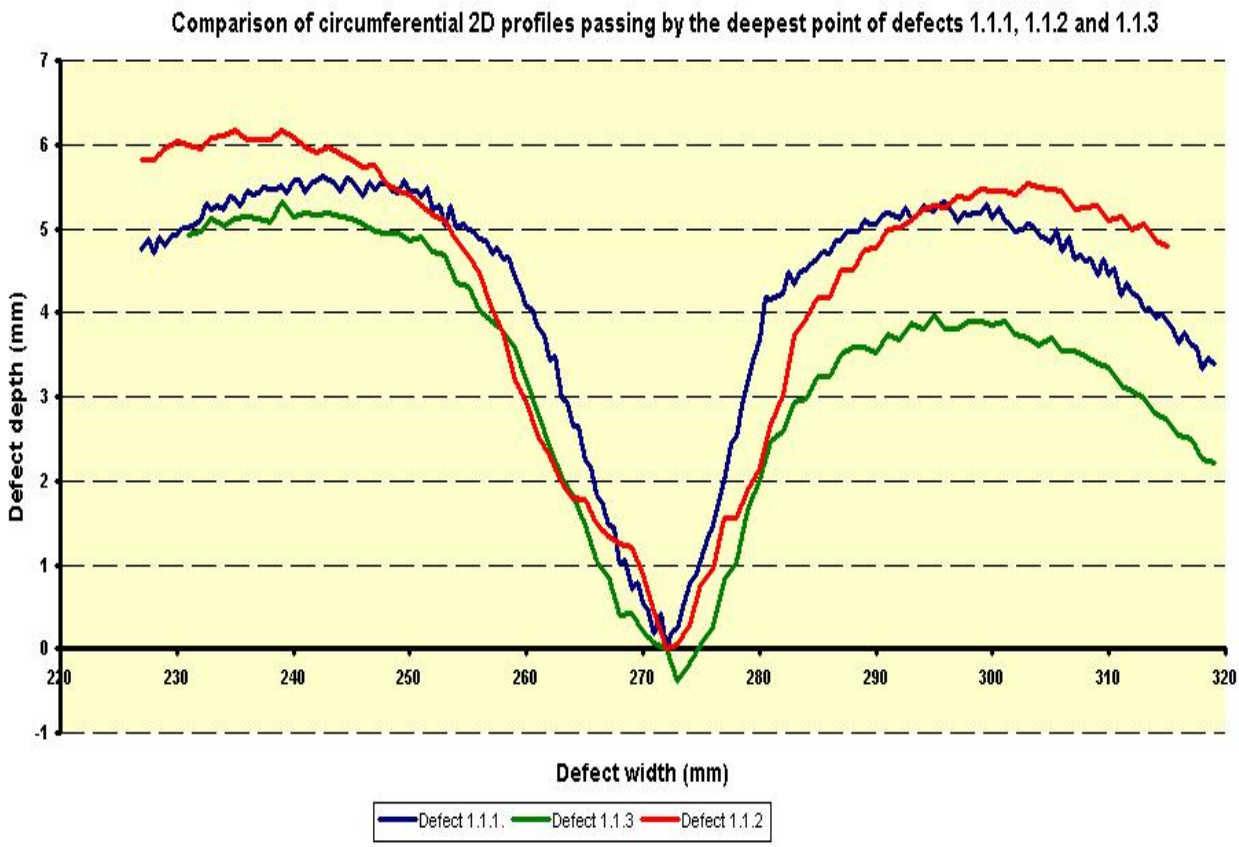
Defect 1.2.1

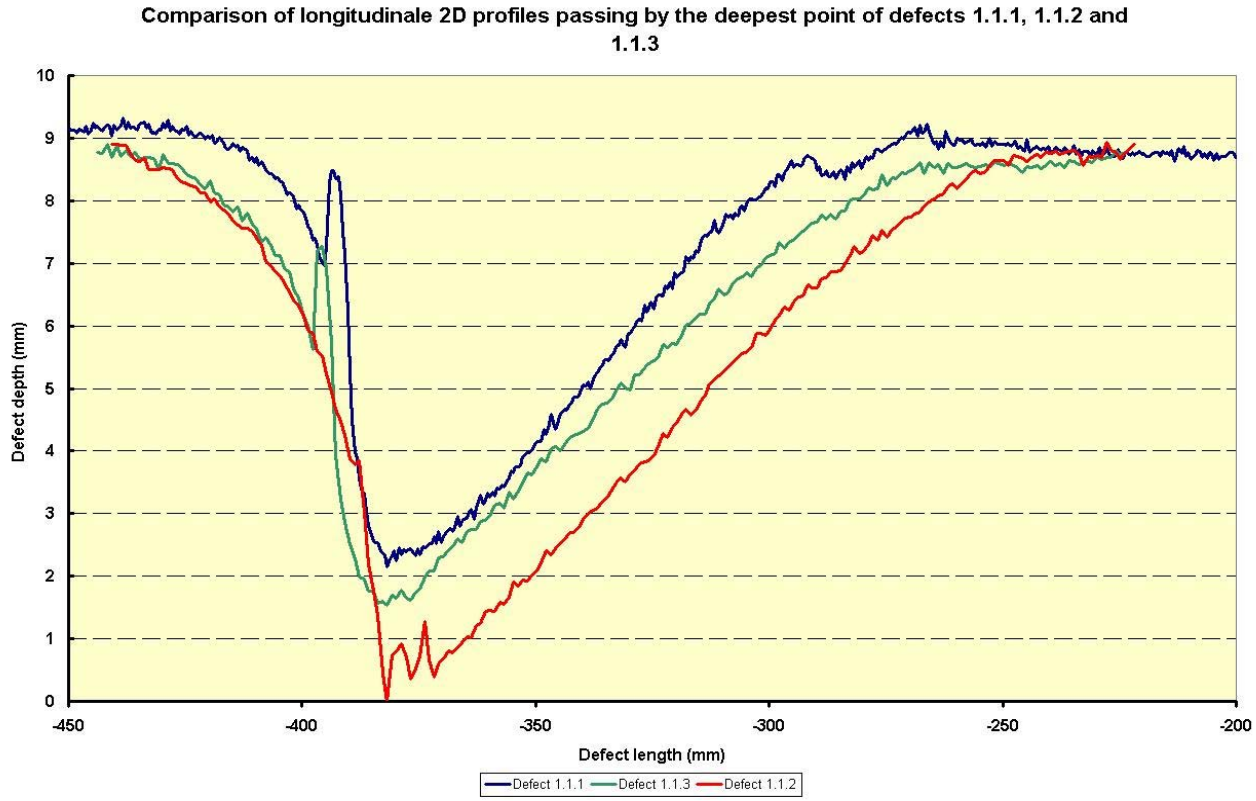


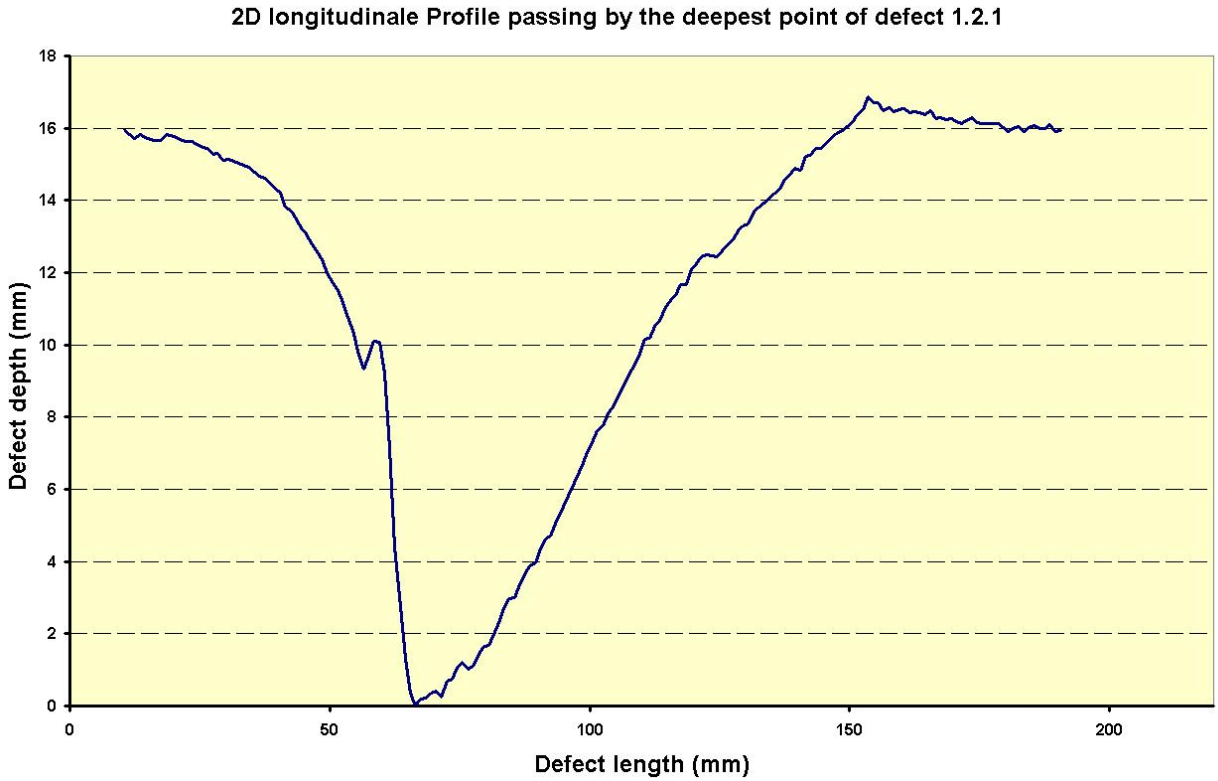
Defect 2.1.1

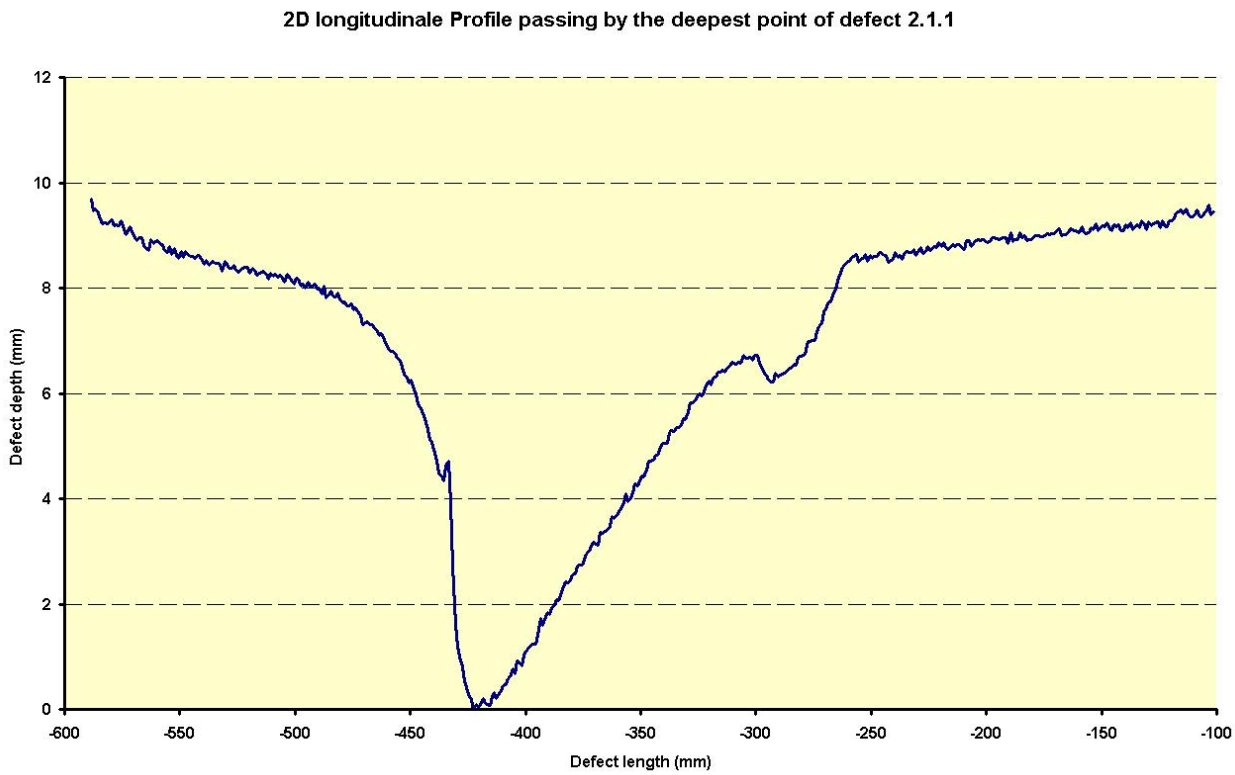
Defects Geometry

Defects have been sized by 3D laser measurements. 2D longitudinal and circumferential profiles passing by the lowest depth of the dent are given in the following figures.

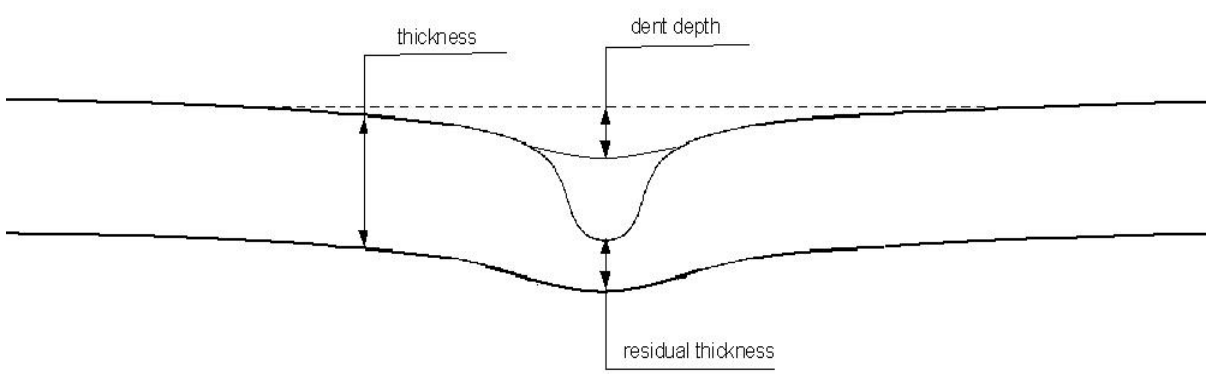



Comparison of longitudinale 2D profiles passing by the deepest point of defects 1.1.1, 1.1.2 and 1.1.3
Defect depth (mm)
Defect length (mm)
Defect 1.1.1
Defect 1.1.3
Defect 1.1.2


2D longitudinale Profile passing by the deepest point of defect 1.2.1
Defect depth (mm)
Defect length (mm)



Along the longitudinal axis of the gouge center, residual thickness has been measured using ultrasonic equipment. Then, the gouge depth has been deduced as indicated in the schematic below.



gouge depth = thickness - residual thickness

The measurements of several key parameters for the defects are summarized in the following table

	Defect Type	Material	Test order	Gouge length (mm)	Gouge depth (%)	Dent depth (%)
Defect 1.1.1	1	Pipe 1	1	128	21	0,84
Defect 1.1.2	1	Pipe 1	3	145	7,5	1,30
Defect 1.1.3	1	Pipe 1	2	135	12,5	1,00
Defect 1.2.1	2	Pipe 1	4	101	42,5	2.08
Defect 2.1.1	1	Pipe 2	5	166	12,5	1.50

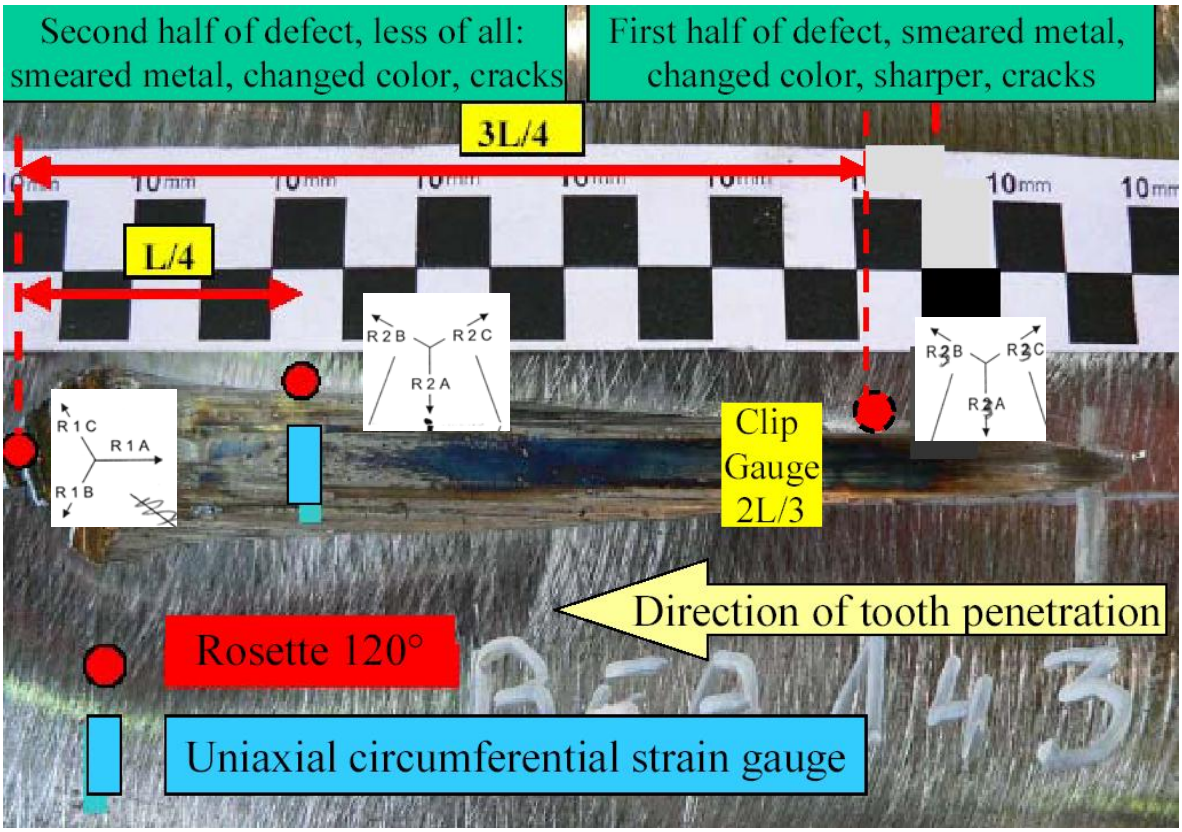
Burst test – defect 1.1.2

Defect 1.1.2 has been instrumented by:

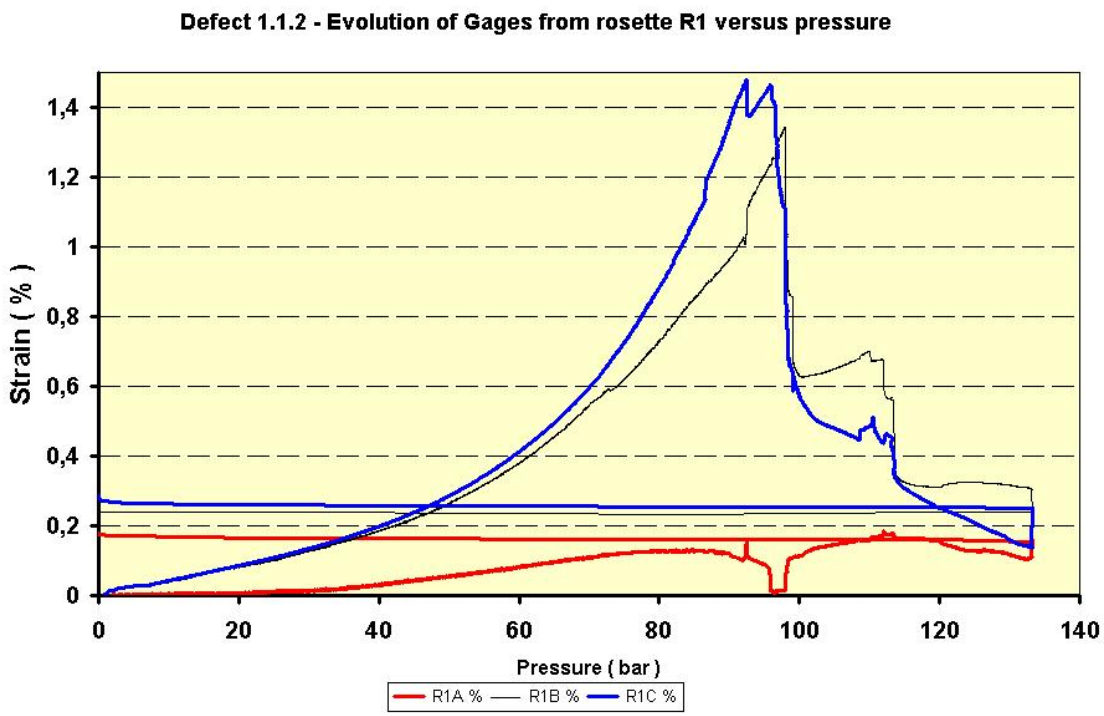
- 1 Clip gage;
- 1 uniaxial circumferential gage in the gouge;
- 3 rosettes at the edge of defect
- 3 rosettes 120° at the edges of defect;
- Uniaxial circumferential gage in the gouge;
- Clip gage close the observed microcrack;
- Potential Drop

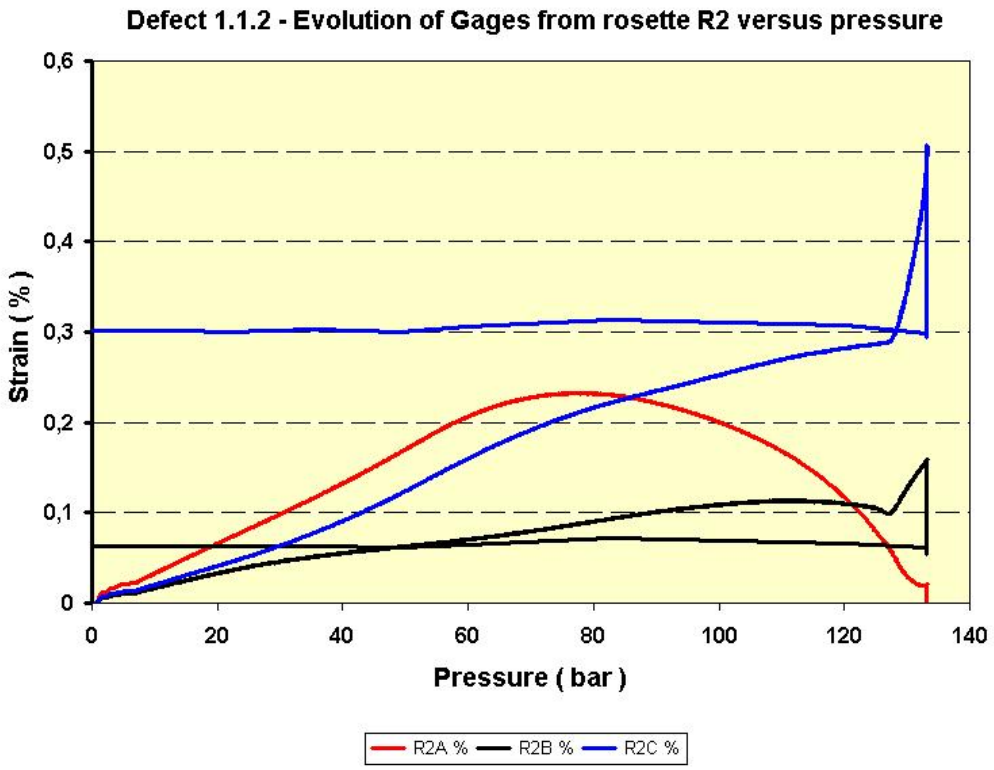
In addition:

- Uniaxial longitudinal and circumferential gages are positioned on the body remote from the defect for the reference;
- Two LVDT on the defect and one on the body for the reference
- Targets along the edge of defect to measure displacement
- Camera

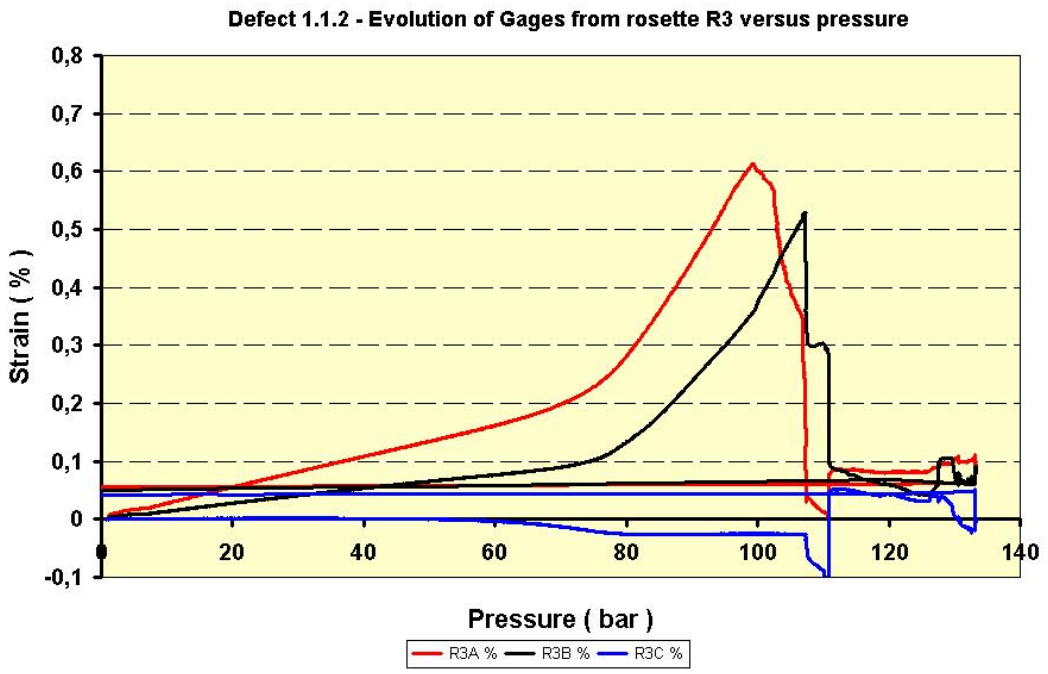


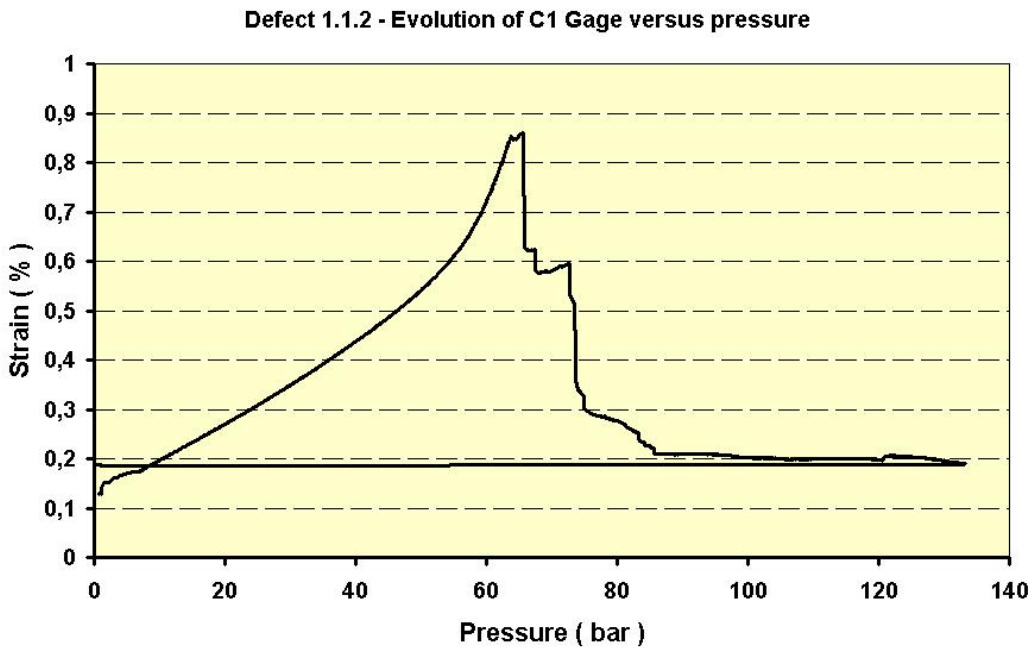
A monotonic internal pressure has been applied and the capacity burst outside of defect 1.1.2 in the body at a pressure corresponding to the critical pressure of pipe without defect

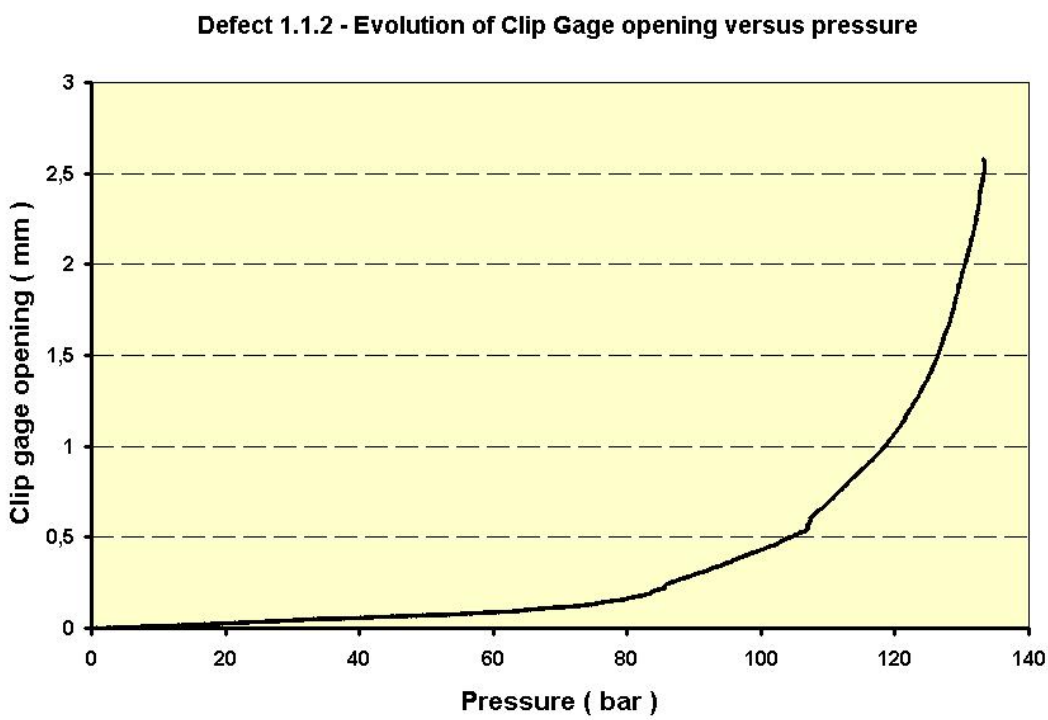


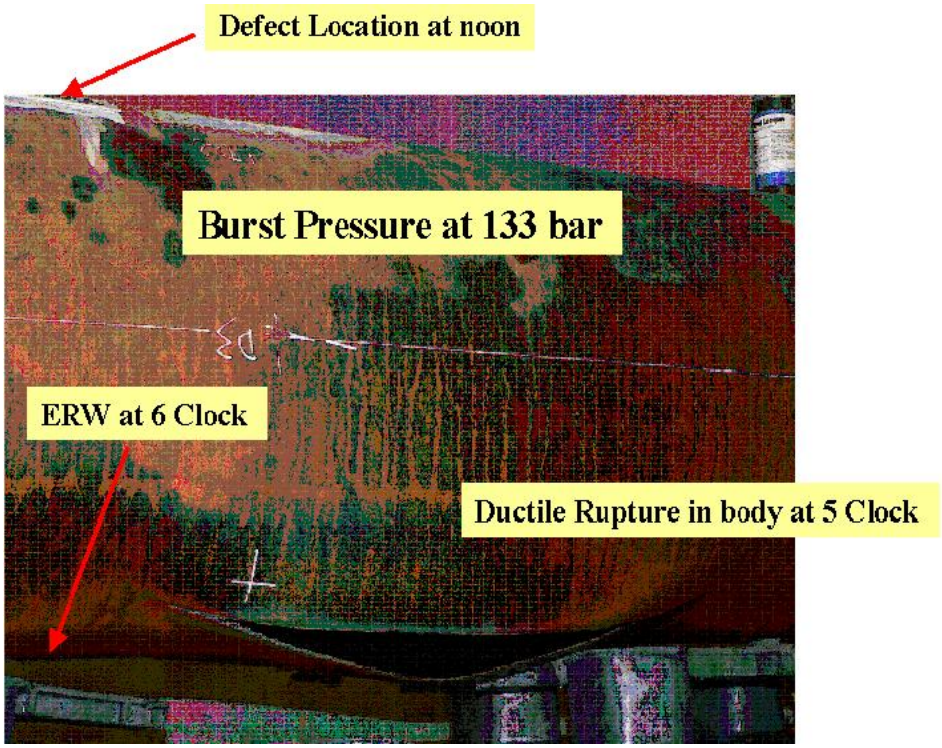

Defect 1.1.2 - Evolution of Gages from rosette R2 versus pressure
Strain (%)
0,6
0,5
0,4
0,3
0,2
0,1
0
0
20
40
60
80
100
120
140
Pressure (bar)
R2A %
R2B %
R2C %

+

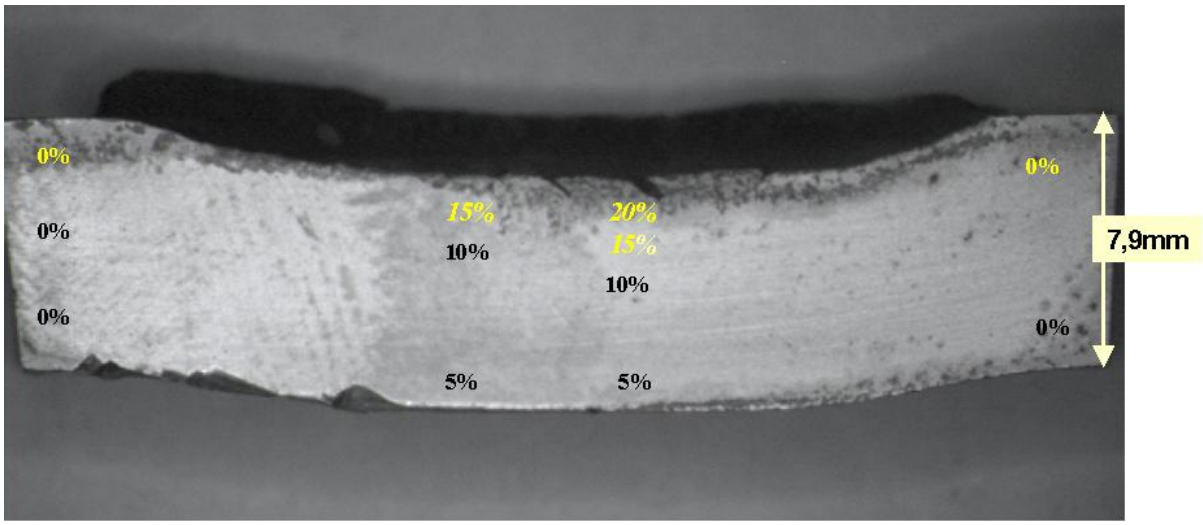

Defect 1.1.2 - Evolution of Gages from rosette R3 versus pressure
Strain (%)
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
-0,1
0
20
40
60
80
100
120
140
Pressure (bar)
R3A %
R3B %
R3C %


Defect 1.1.2 - Evolution of C1 Gage versus pressure
Strain (%)
Pressure (bar)
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1
0
20
40
60
80
100
120
140

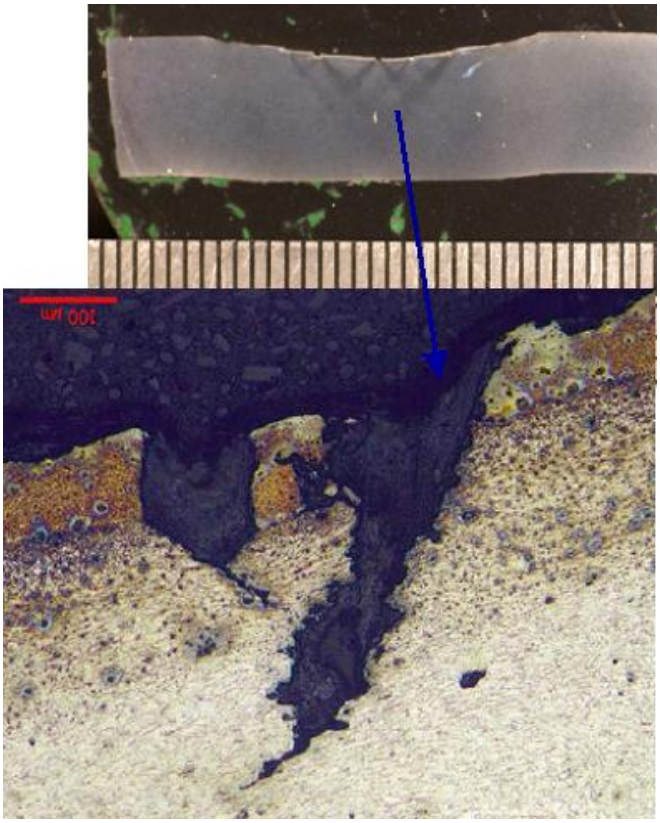

Defect 1.1.2 - Evolution of Clip Gage opening versus pressure
Clip gage opening (mm)
Pressure (bar)
0
0,5
1
1,5
2
2,5
3
0
20
40
60
80
100
120
140



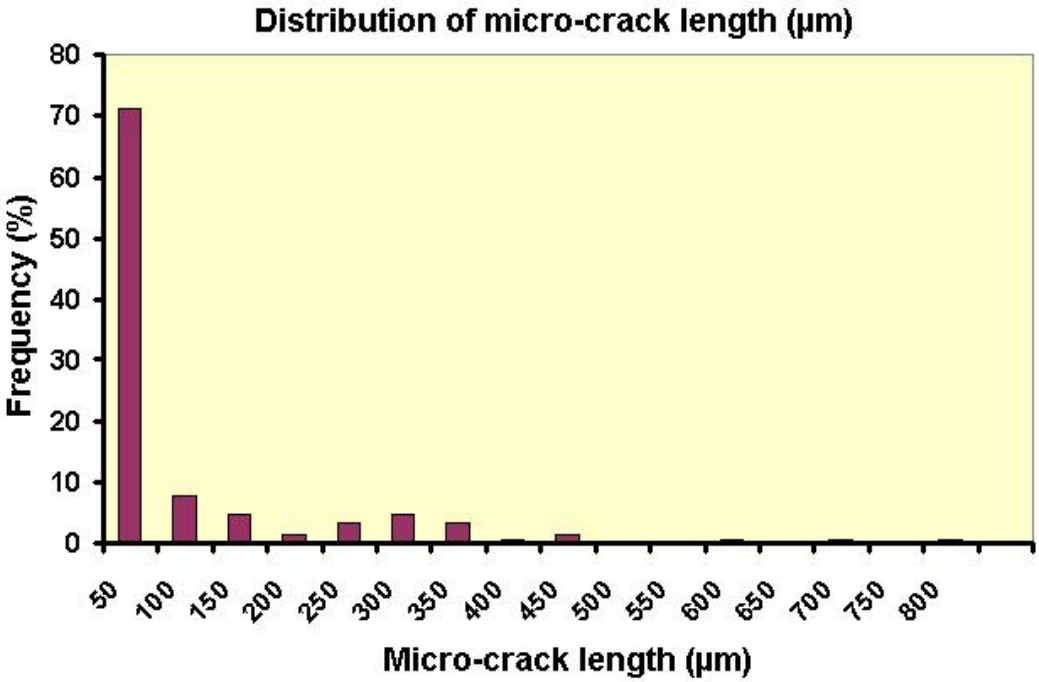
The defect 1.1.2 has been metallurgically investigated after completing the burst test. Note, the burst failure did not occur at the location of the defect. The pipe has been cut in ten transverse strip bands where the defect is present. On each strip, by optical microscope, metallurgical observation of microstructure, size of micro-cracks and rough estimation of strain by micro-hardness calibration under the defect has been done.



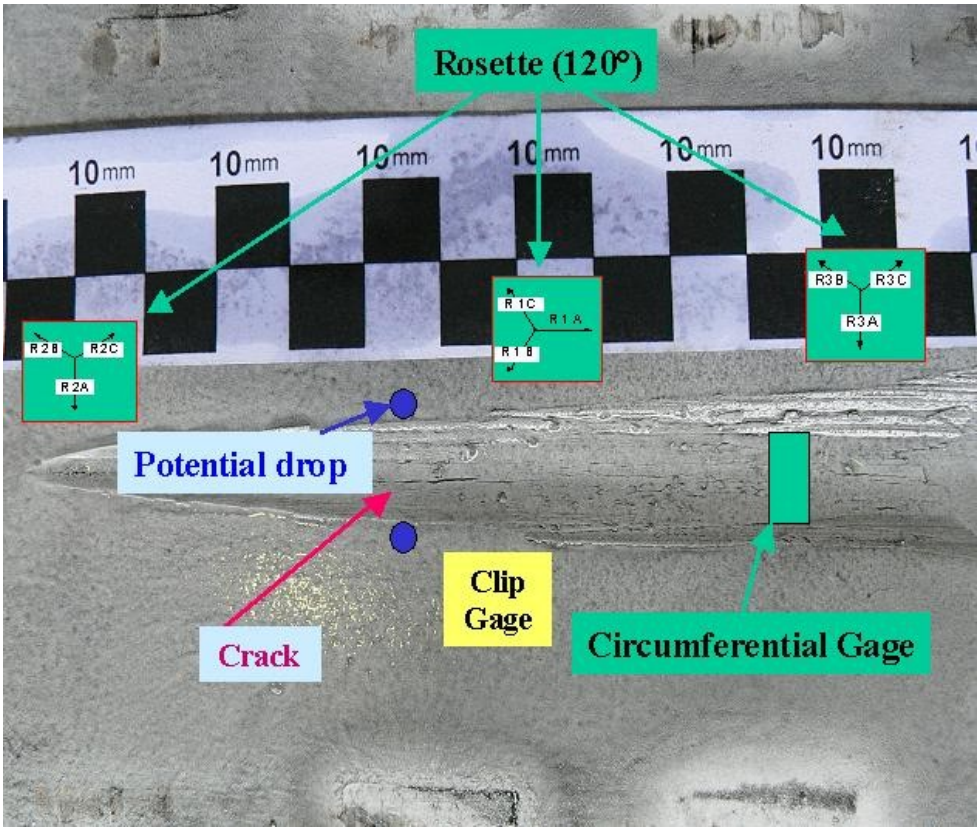
Strain experimentally estimated around 15-20 % close to the defect 1.1.2 surface.

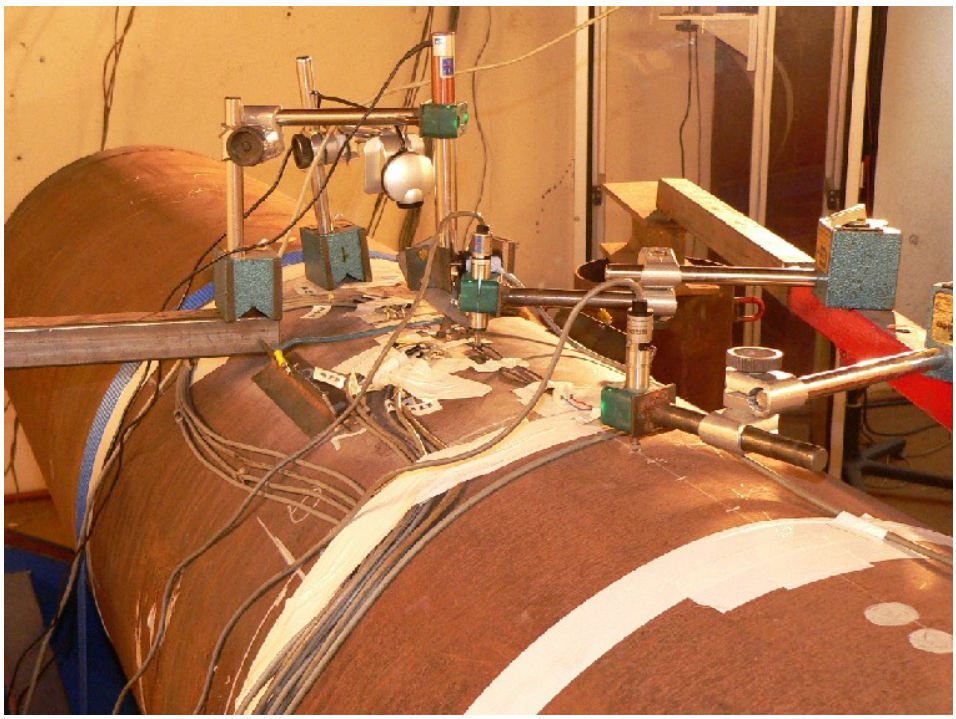


View of notch, micro-cracks and change of microstructure at the surface

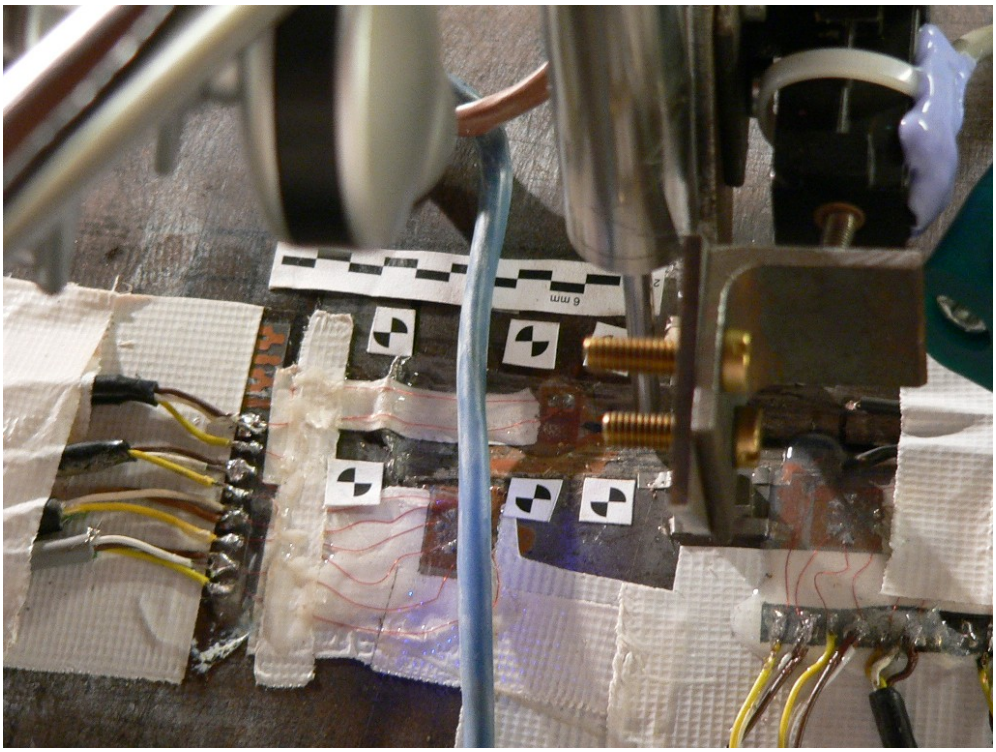


Fatigue test – defect 1.1.3
Instrumentation





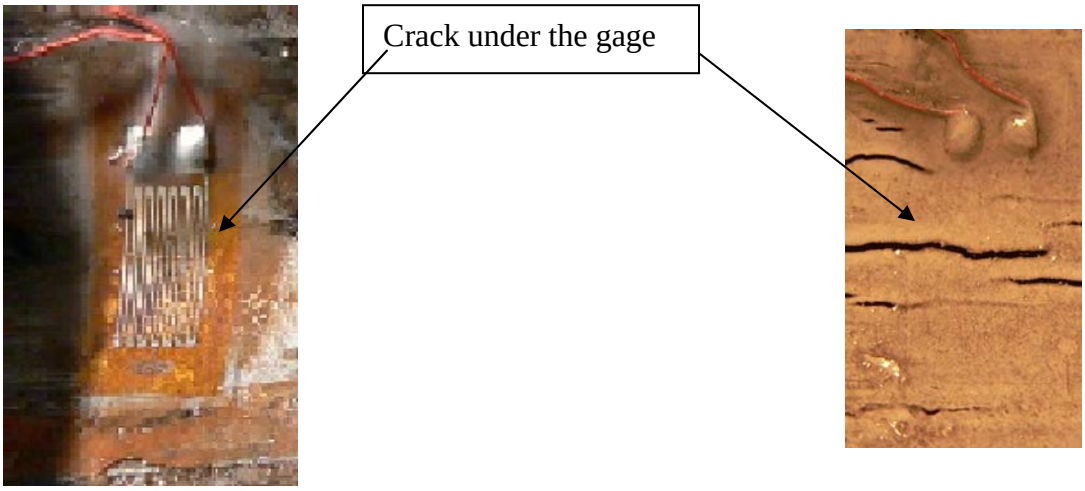
General view of defect instrumentation



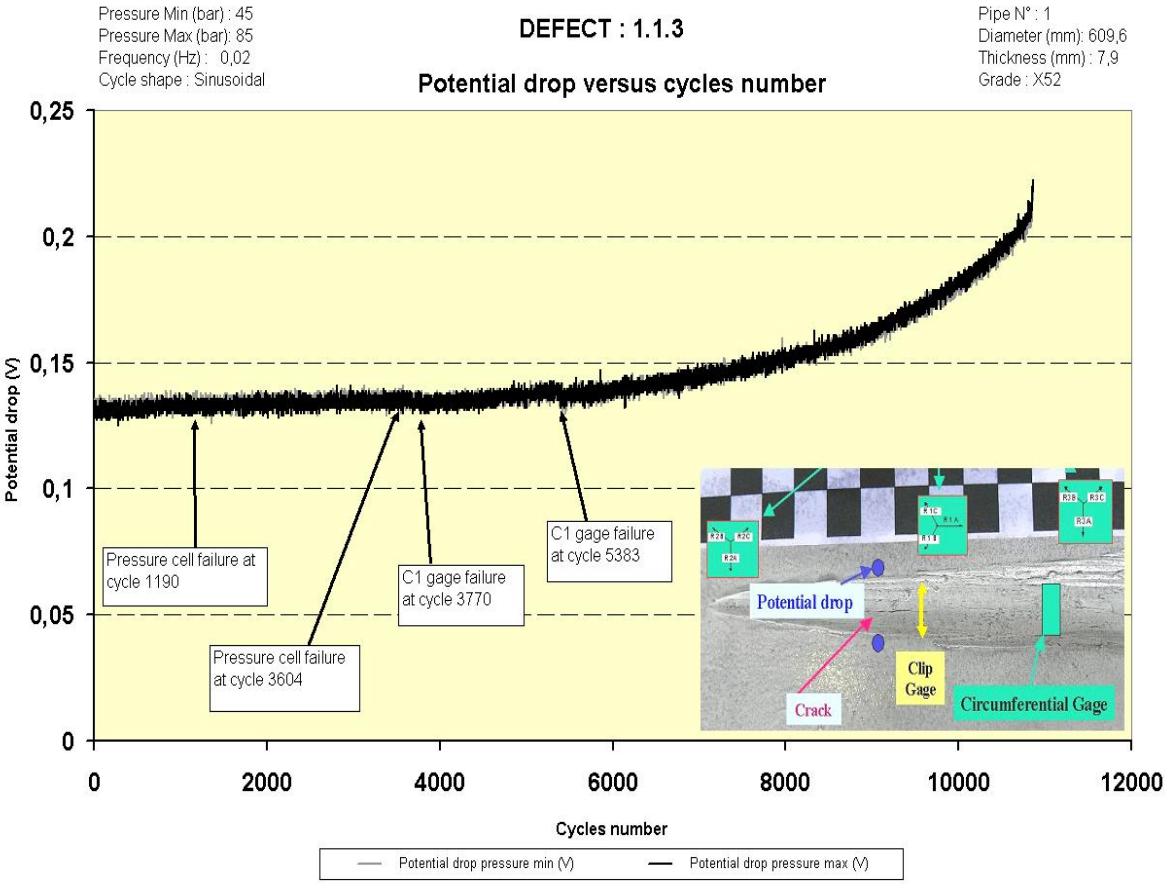
Detailed View focused on circumferential gage, displacement and clip gages

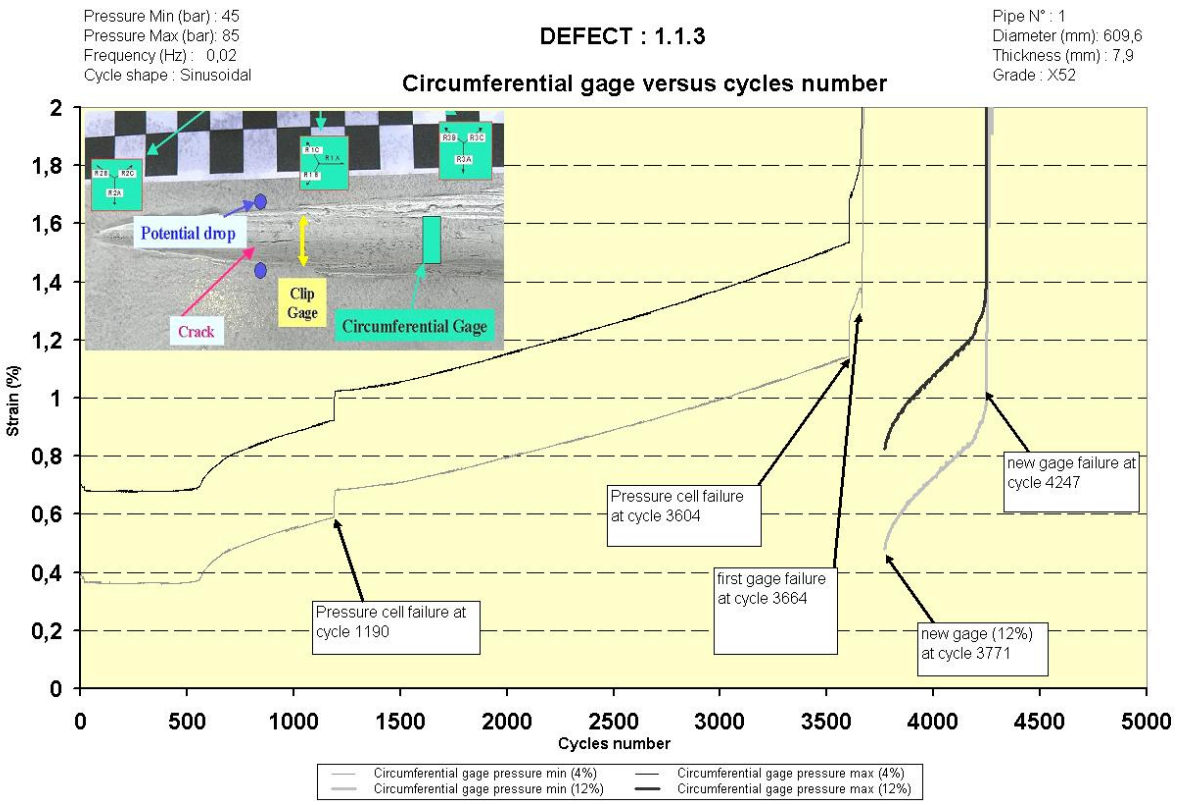
The pressure variation has been controlled between 45 bar and 85 bar with a sinusoidal shape and a frequency of 0.02 Hz. The failure is reached between 10,480 cycles and 10,869 cycles. The history of the fatigue test is the following:

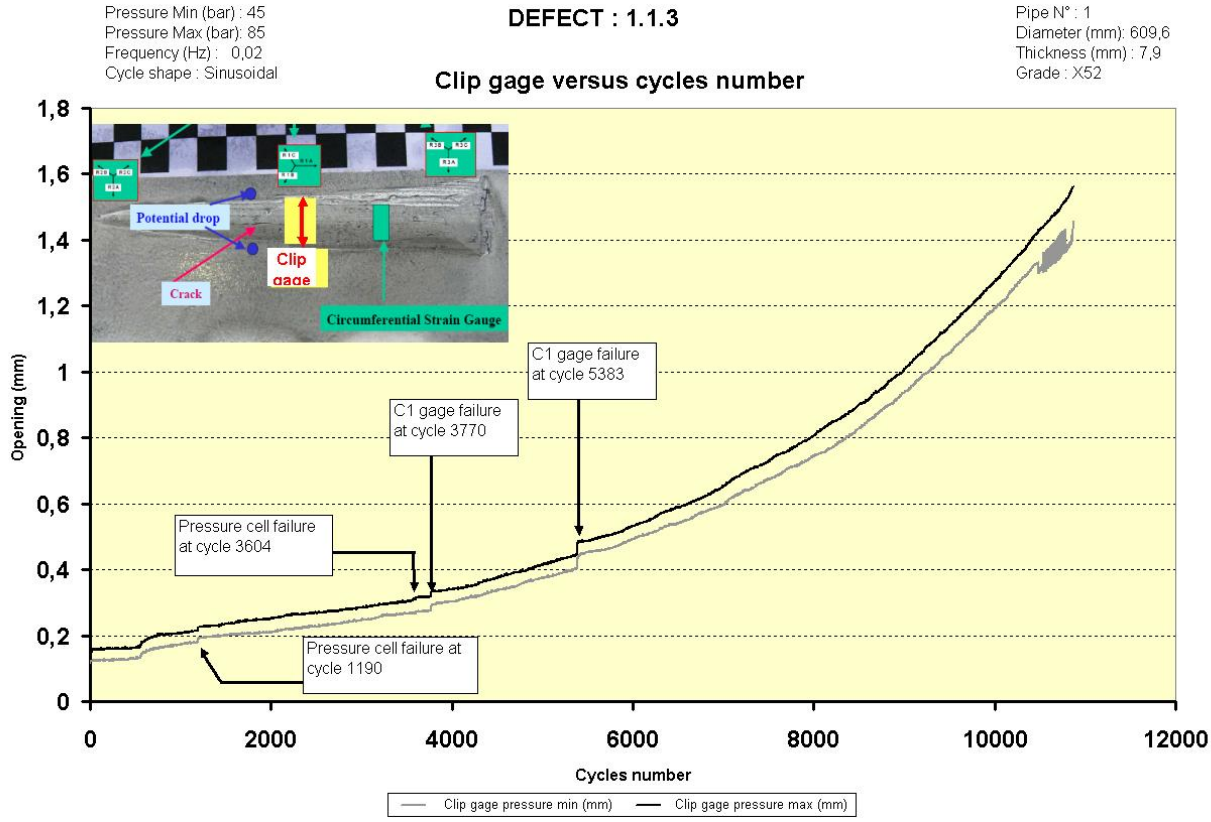
- Cycle 0 to cycle 1190 : 45bar-85bar;
- **Interruption test at cycle 1190 - 0bar**: Pressure cell failure;
- Cycle 1191 to cycle 3604 : 45bar-85bar;
- **Interruption test at cycle 3604 – 0 bar:** Pressure cell failure;
- **Cycle 3664** – 45bar-85bar : the circumferential gage in gouge has failed;
- Cycle 3664 to cycle 3770 : 45bar-85bar;
- **Interruption test at cycle 3770 – 0bar:** Replace of failed circumferential gage in the gouge;
- **Cycle 4247** –45bar-85bar: the second circumferential gage in gouge has failed;
- Cycle 4247 to cycle 5380: 45bar-85bar;
- **Interruption test at cycle 5380 – 0bar:** Check and remove the second failed circumferential gage. A crack has been observed under the gage in the gouge.

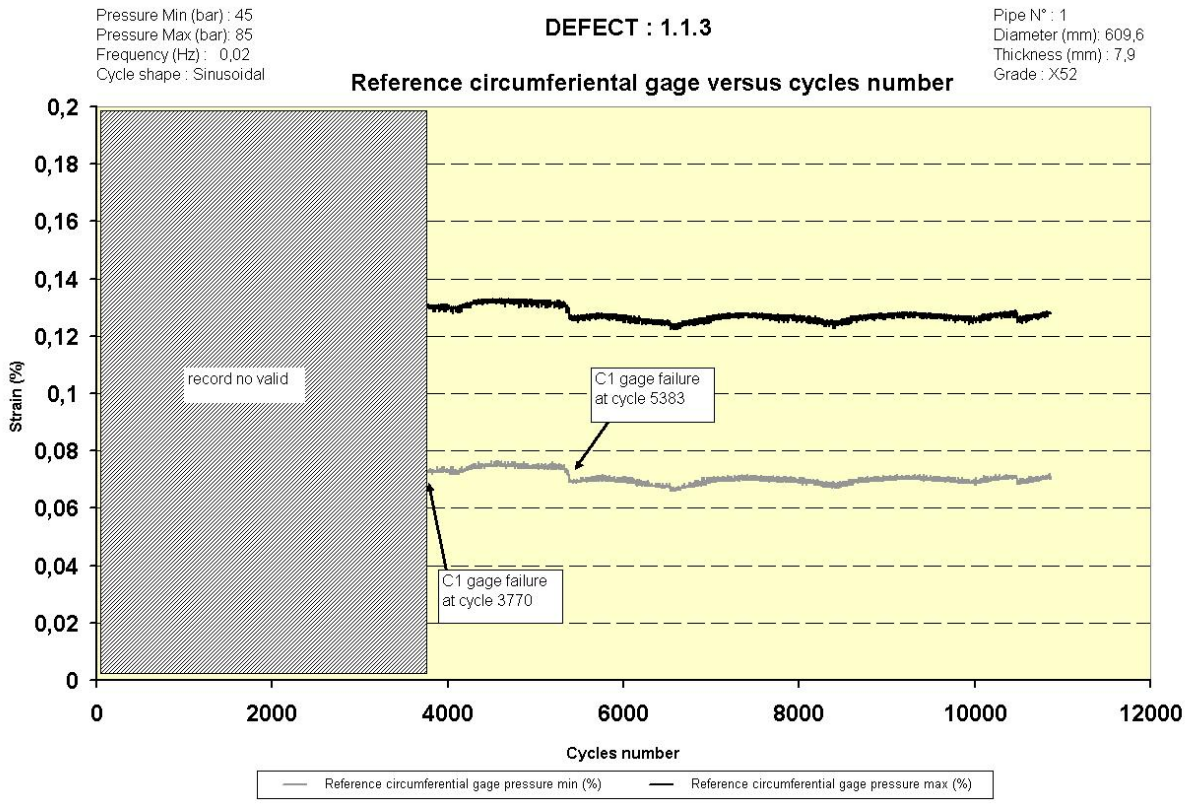


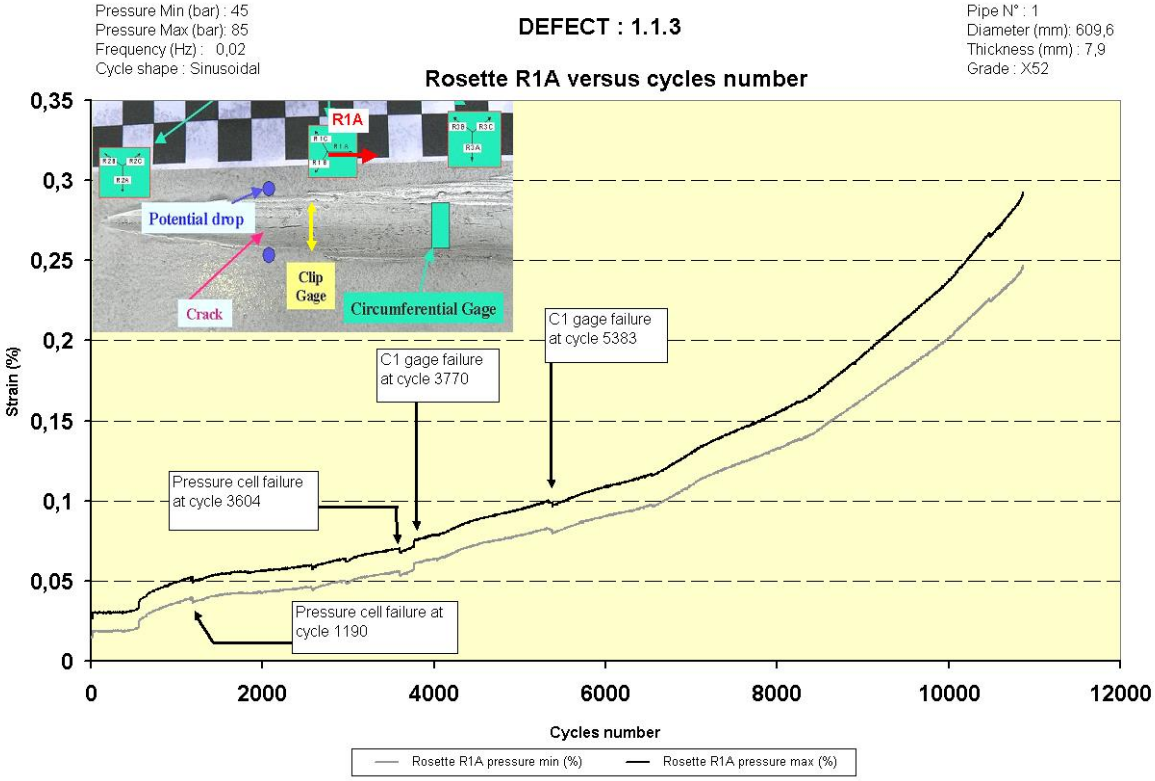
- Cycle 5381 to cycle 10480 or 10869 : 45bar-85bar
- **Between cycle 10480 and cycle 10869 :** Failure in the defect 1.1.3.

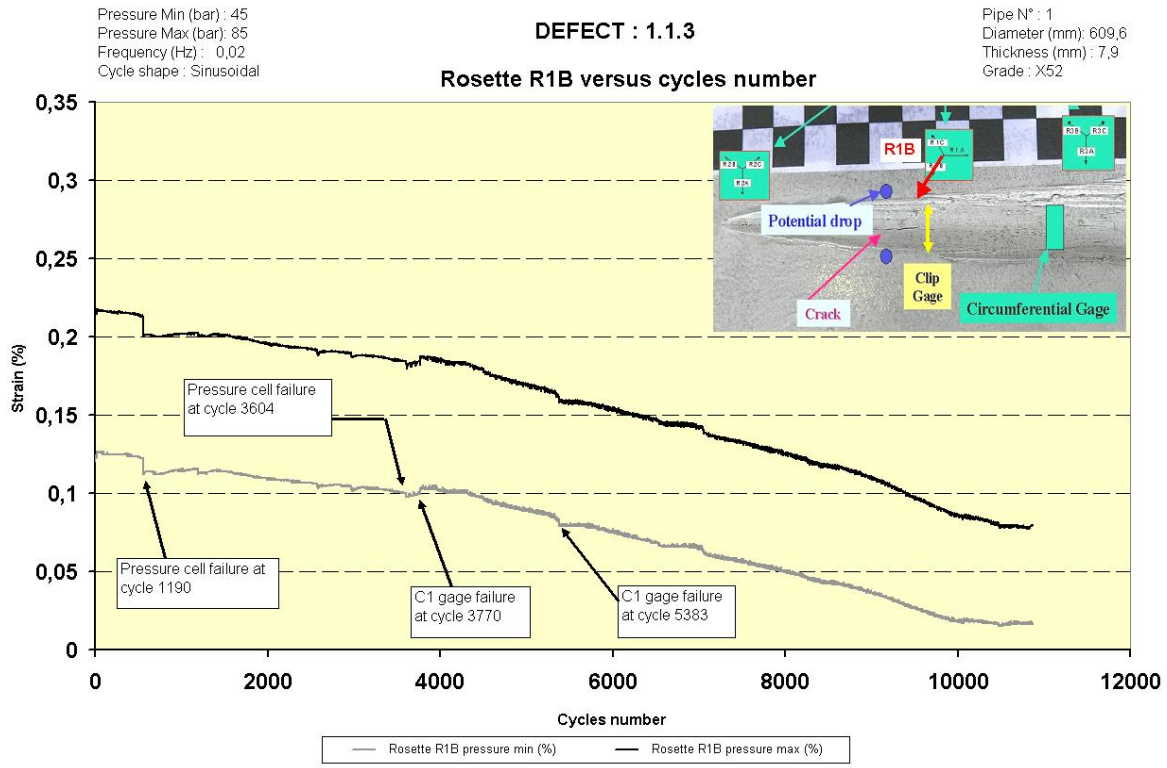


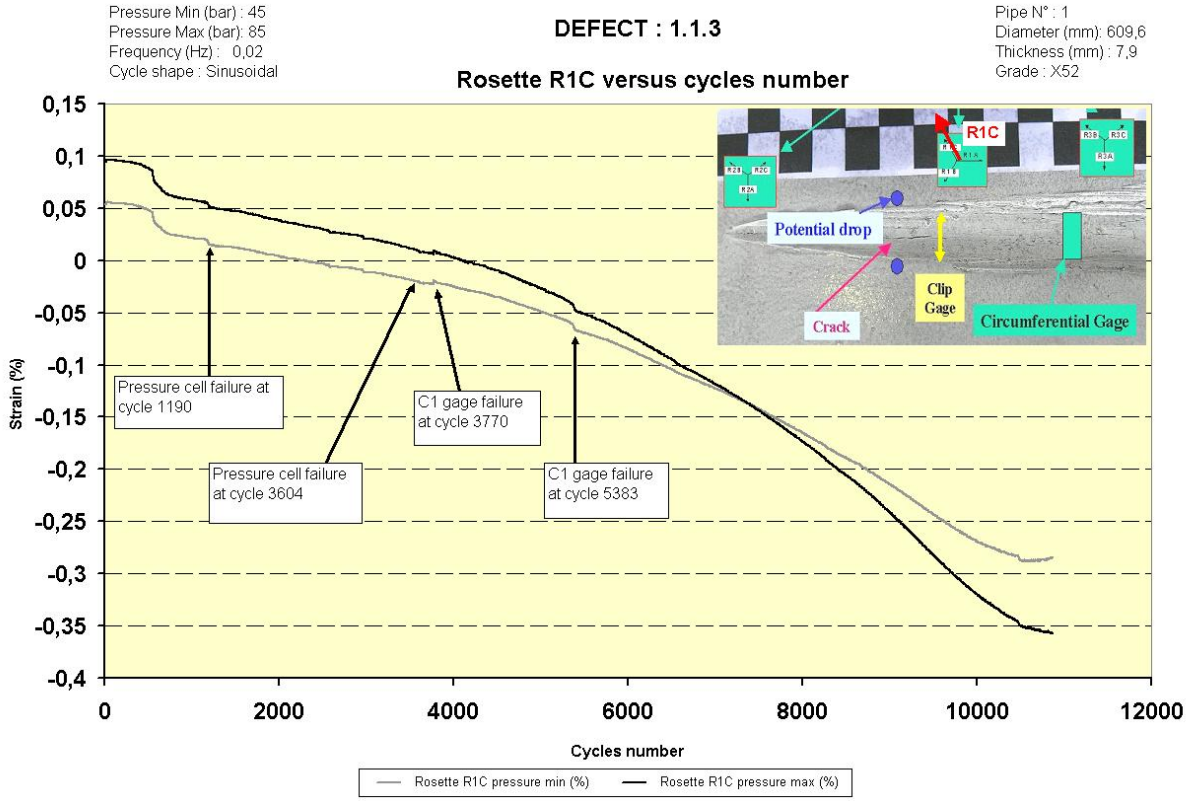

Pressure Min (bar) : 45
Pressure Max (bar): 85
Frequency (Hz) : 0,02
Cycle shape : Sinusoidal
DEFECT : 1.1.3
Circumferential gage versus cycles number
Pipe N° : 1
Diameter (mm): 609,6
Thickness (mm) : 7,9
Grade : X52
Potential drop
Crack
Clip Gage
Circumferential Gage
Pressure cell failure at cycle 1190
Pressure cell failure at cycle 3604
first gage failure at cycle 3664
new gage (12%) at cycle 3771
new gage failure at cycle 4247
Strain (%)
Cycles number
Circumferential gage pressure min (4%)
Circumferential gage pressure min (12%)
Circumferential gage pressure max (4%)
Circumferential gage pressure max (12%)

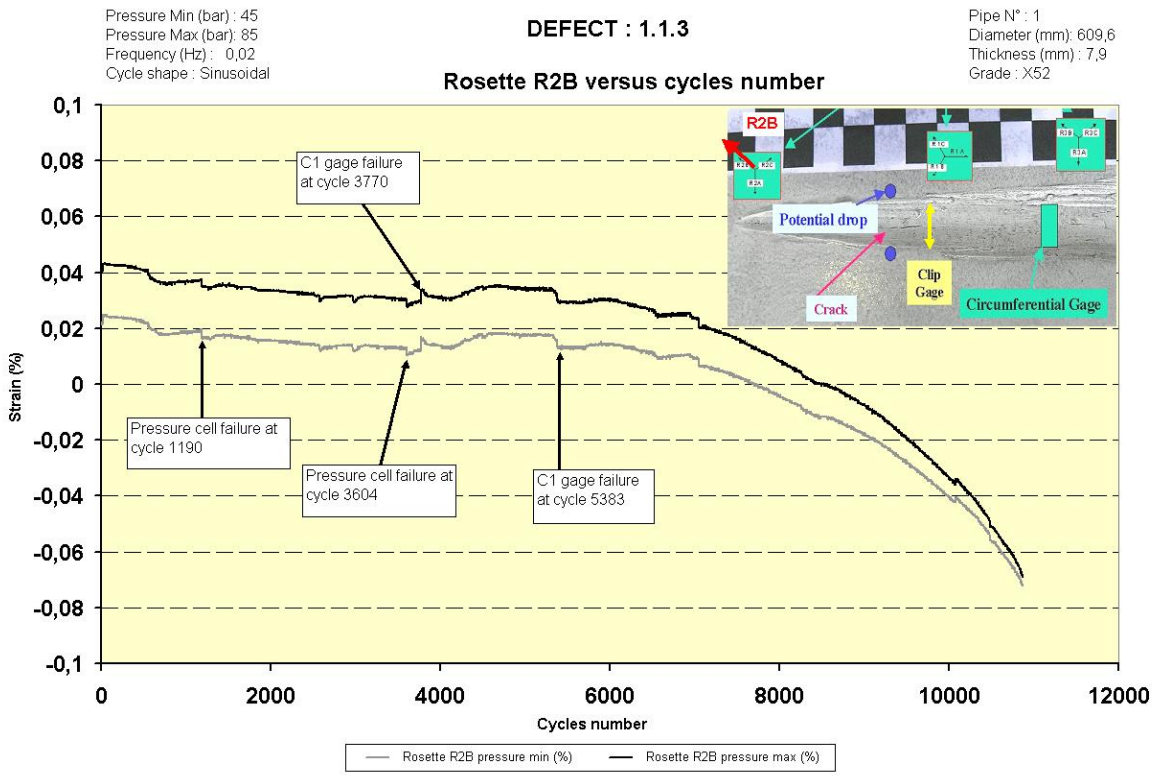

Pressure Min (bar) : 45
Pressure Max (bar): 85
Frequency (Hz) : 0,02
Cycle shape : Sinusoidal
DEFECT : 1.1.3
Clip gage versus cycles number
Pipe N° : 1
Diameter (mm): 609,6
Thickness (mm) : 7,9
Grade : X52
Potential drop
Crack
Clip gage
Circumferential Strain Gauge
C1 gage failure at cycle 5383
C1 gage failure at cycle 3770
Pressure cell failure at cycle 3604
Pressure cell failure at cycle 1190
Opening (mm)
Cycles number
Clip gage pressure min (mm)
Clip gage pressure max (mm)

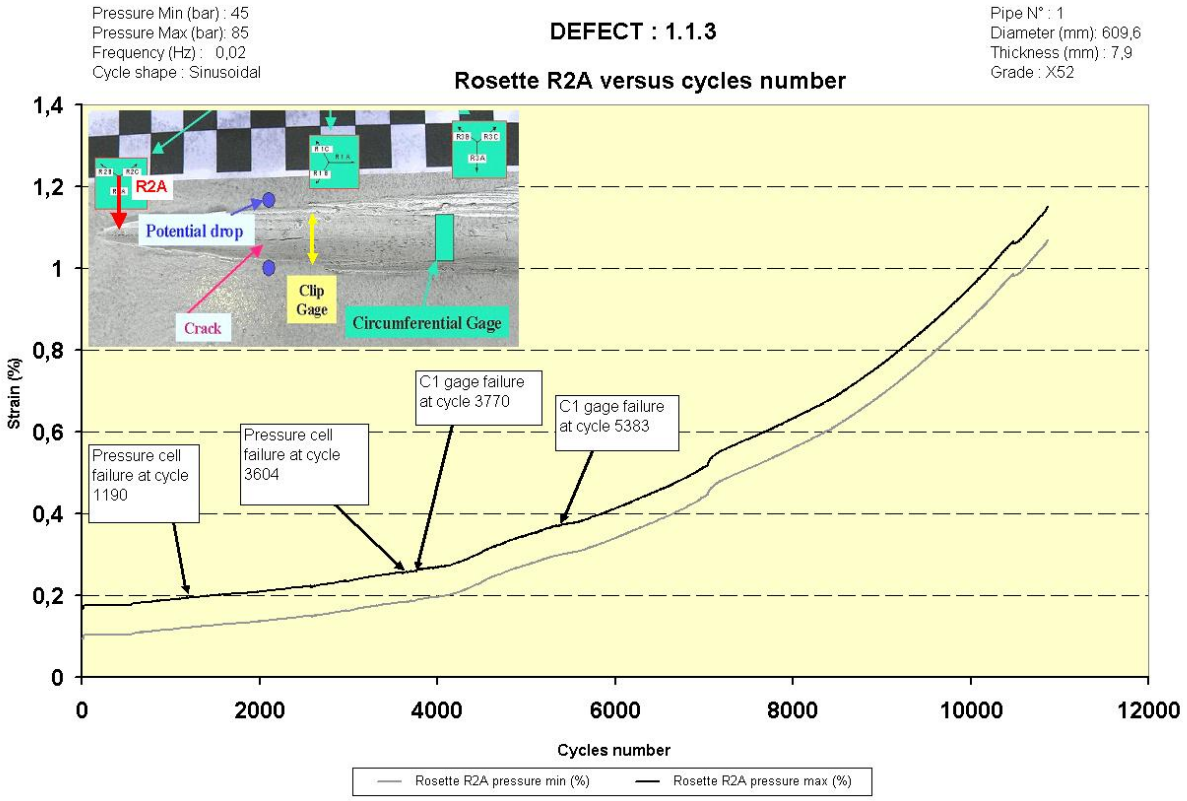

Pressure Min (bar) : 45
Pressure Max (bar): 85
Frequency (Hz) : 0,02
Cycle shape : Sinusoidal
DEFECT : 1.1.3
Pipe N° : 1
Diameter (mm): 609,6
Thickness (mm) : 7,9
Grade : X52
Reference circumferiental gage versus cycles number
Strain (%)
record no valid
C1 gage failure at cycle 5383
C1 gage failure at cycle 3770
Cycles number
Reference circumferential gage pressure min (%)
Reference circumferential gage pressure max (%)

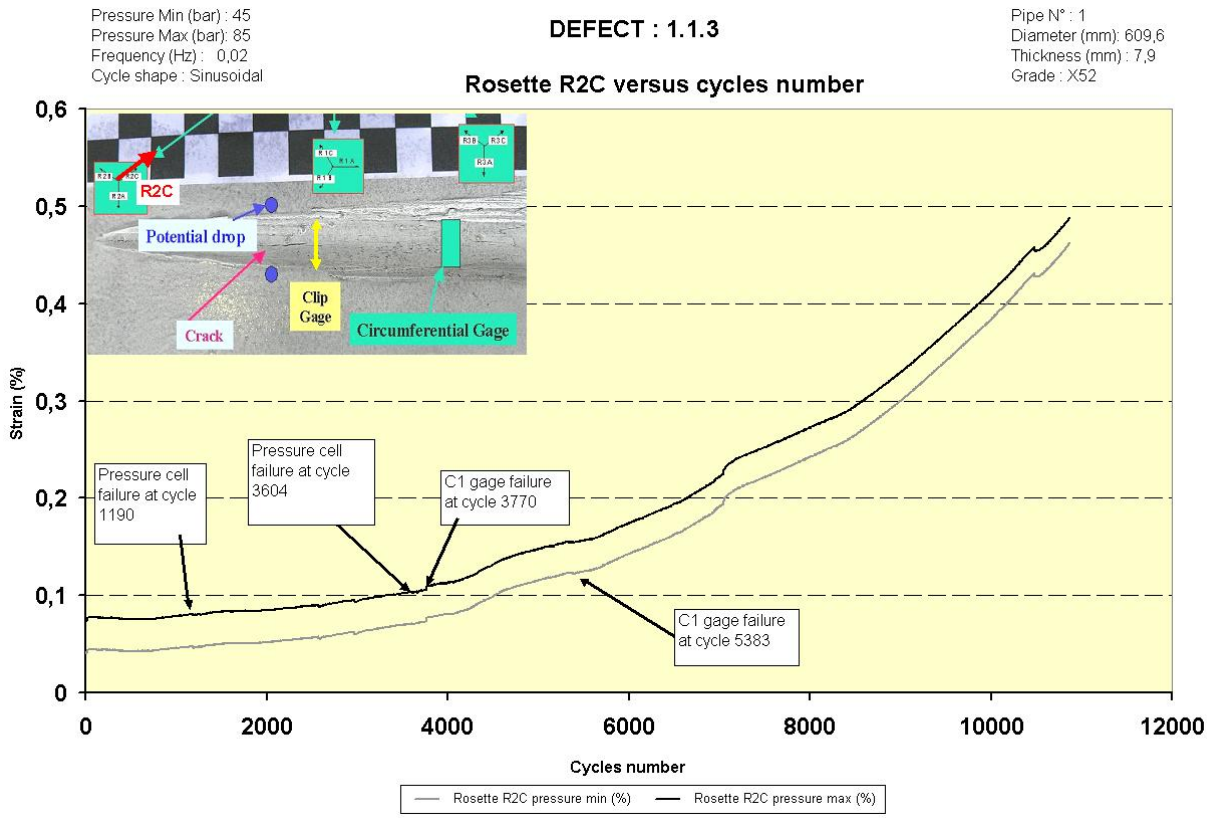

Pressure Min (bar) : 45
Pressure Max (bar): 85
Frequency (Hz) : 0,02
Cycle shape : Sinusoidal
DEFECT : 1.1.3
Pipe N° : 1
Diameter (mm): 609,6
Thickness (mm) : 7,9
Grade : X52
Rosette R1A versus cycles number
R1A
Potential drop
Clip Gage
Crack
Circumferential Gage
Strain (%)
C1 gage failure at cycle 5383
C1 gage failure at cycle 3770
Pressure cell failure at cycle 3604
Pressure cell failure at cycle 1190
Cycles number
Rosette R1A pressure min (%)
Rosette R1A pressure max (%)


Pressure Min (bar) : 45
Pressure Max (bar): 85
Frequency (Hz) : 0,02
Cycle shape : Sinusoidal
DEFECT : 1.1.3
Rosette R1B versus cycles number
Pipe N° : 1
Diameter (mm): 609,6
Thickness (mm) : 7,9
Grade : X52
R1B
Potential drop
Crack
Clip Gage
Circumferential Gage
Pressure cell failure at cycle 3604
Pressure cell failure at cycle 1190
C1 gage failure at cycle 3770
C1 gage failure at cycle 5383
Strain (%)
Cycles number
Rosette R1B pressure min (%)
Rosette R1B pressure max (%)

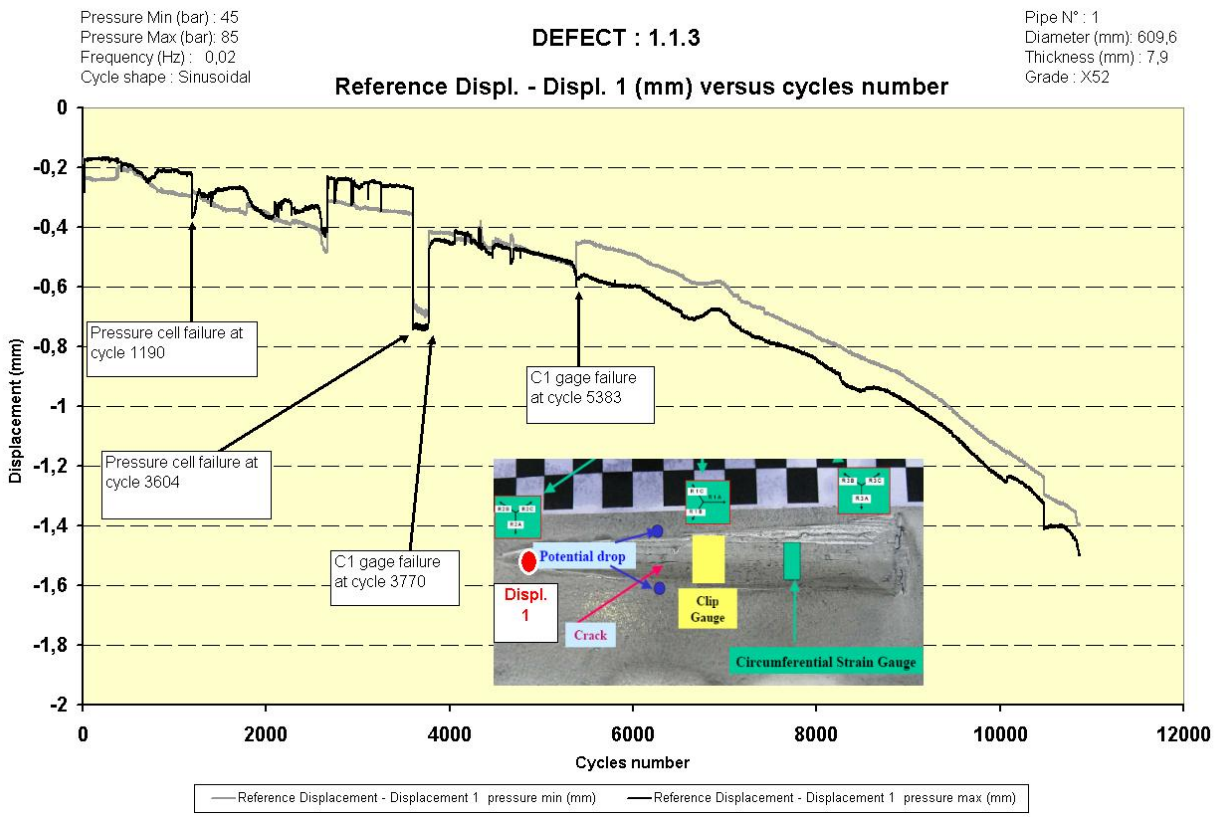

Pressure Min (bar) : 45
Pressure Max (bar): 85
Frequency (Hz) : 0,02
Cycle shape : Sinusoidal
DEFECT : 1.1.3
Rosette R1C versus cycles number
Pipe N° : 1
Diameter (mm): 609,6
Thickness (mm) : 7,9
Grade : X52
R1C
Potential drop
Crack
Clip Gage
Circumferential Gage
Pressure cell failure at cycle 1190
C1 gage failure at cycle 3770
Pressure cell failure at cycle 3604
C1 gage failure at cycle 5383
Strain (%)
Cycles number
Rosette R1C pressure min (%)
Rosette R1C pressure max (%)

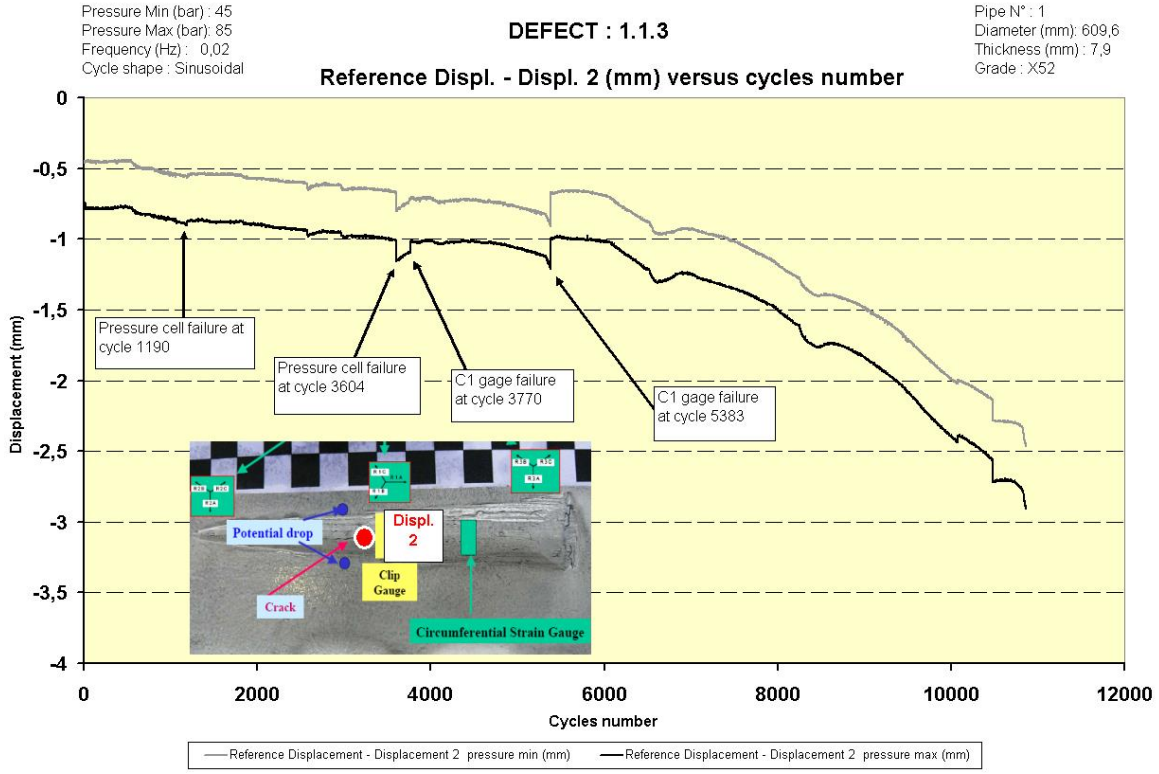

Pressure Min (bar) : 45
Pressure Max (bar): 85
Frequency (Hz) : 0,02
Cycle shape : Sinusoidal
DEFECT : 1.1.3
Pipe N° : 1
Diameter (mm): 609,6
Thickness (mm) : 7,9
Grade : X52
Rosette R2B versus cycles number
R2B
Potential drop
Crack
Clip Gage
Circumferential Gage
C1 gage failure at cycle 3770
Pressure cell failure at cycle 1190
Pressure cell failure at cycle 3604
C1 gage failure at cycle 5383
Strain (%)
Cycles number
Rosette R2B pressure min (%)
Rosette R2B pressure max (%)


Pressure Min (bar) : 45
Pressure Max (bar): 85
Frequency (Hz) : 0,02
Cycle shape : Sinusoidal
DEFECT : 1.1.3
Pipe N° : 1
Diameter (mm): 609,6
Thickness (mm) : 7,9
Grade : X52
Rosette R2A versus cycles number
R2A
Potential drop
Crack
Clip Gage
Circumferential Gage
C1 gage failure at cycle 3770
C1 gage failure at cycle 5383
Pressure cell failure at cycle 1190
Pressure cell failure at cycle 3604
Strain (%)
Cycles number
Rosette R2A pressure min (%)
Rosette R2A pressure max (%)

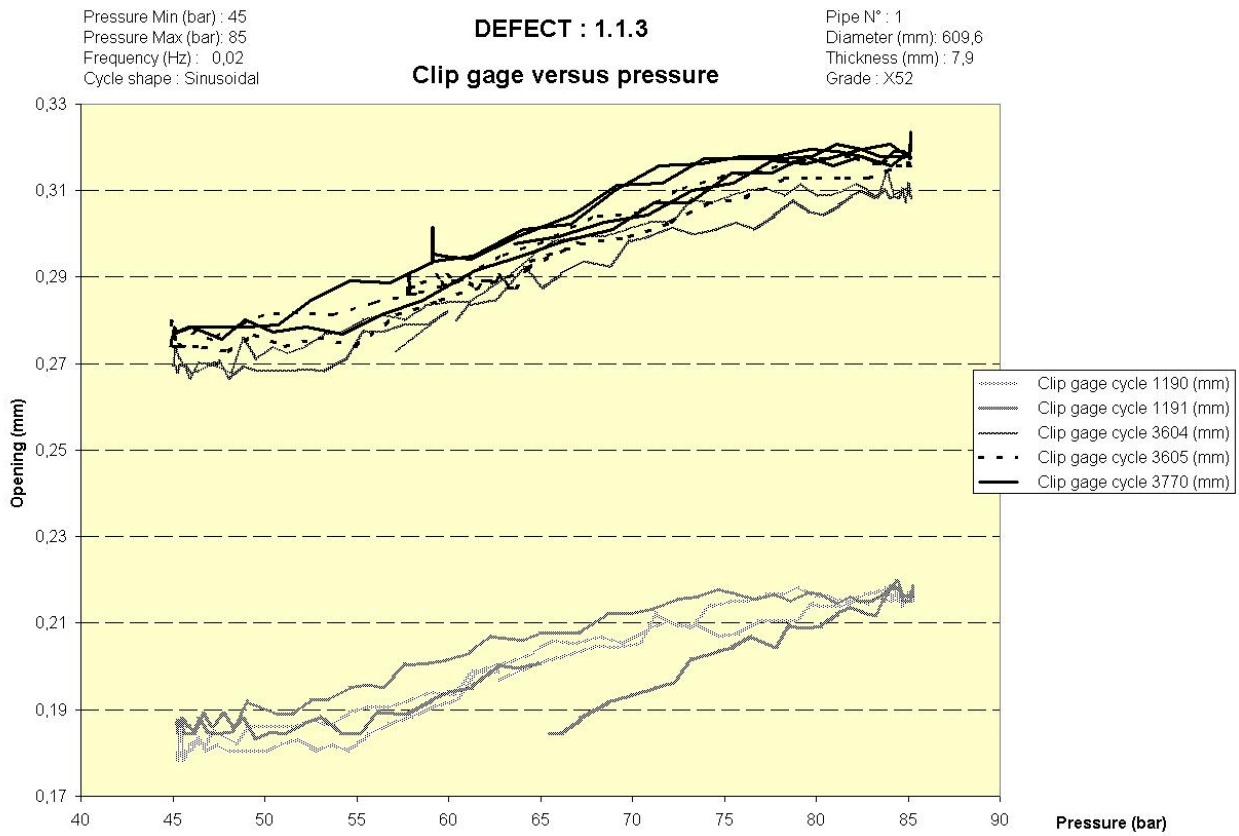


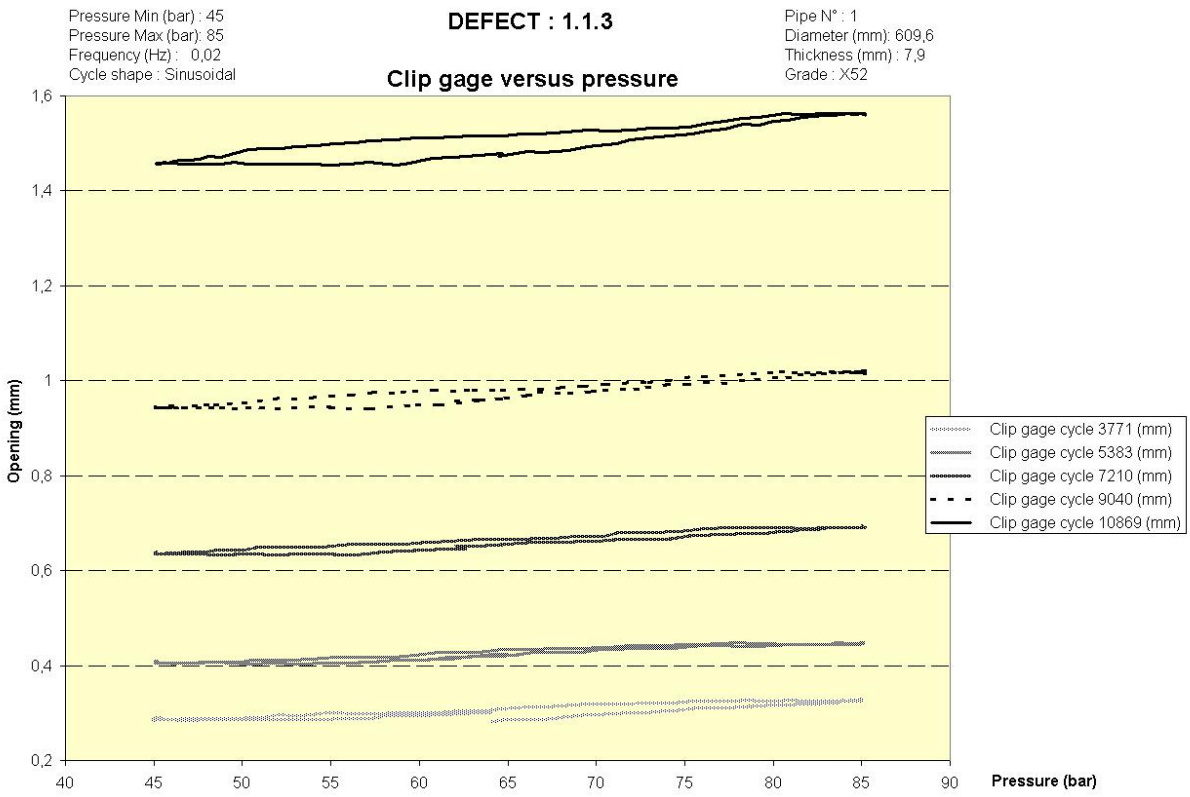
The next curves provide evolution of LVDT1 and LVDT2 displacements positioned in the defect comparatively to the $LVDT_{reference}$ on the body capacity. This is why the vertical axes are the difference between the LVDT1 or LVDT2 displacements and the $LVDT_{reference}$ displacement.

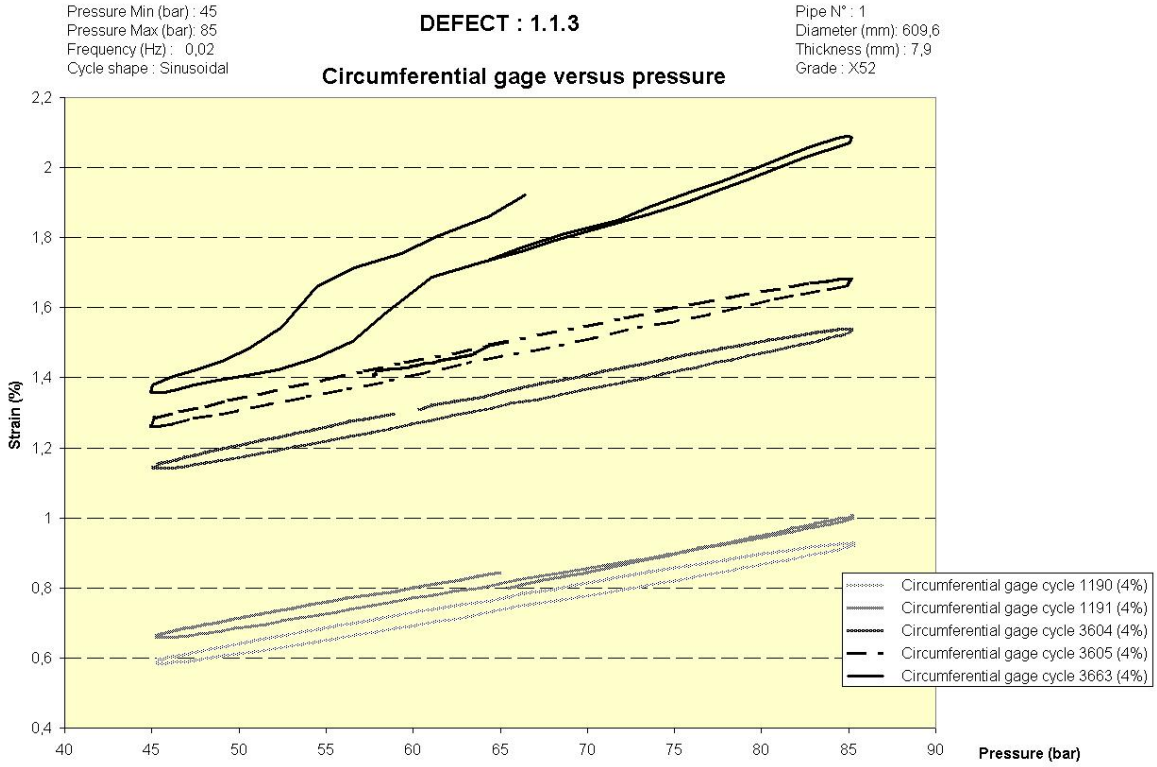

Pressure Min (bar) : 45
Pressure Max (bar): 85
Frequency (Hz) : 0,02
Cycle shape : Sinusoidal
DEFECT : 1.1.3
Reference Displ. - Displ. 1 (mm) versus cycles number
Pipe N° : 1
Diameter (mm): 609,6
Thickness (mm) : 7,9
Grade : X52
Displacement (mm)
Cycles number
Pressure cell failure at cycle 1190
Pressure cell failure at cycle 3604
C1 gage failure at cycle 3770
C1 gage failure at cycle 5383
Potential drop
Displ. 1
Crack
Clip Gauge
Circumferential Strain Gauge
Reference Displacement - Displacement 1 pressure min (mm)
Reference Displacement - Displacement 1 pressure max (mm)

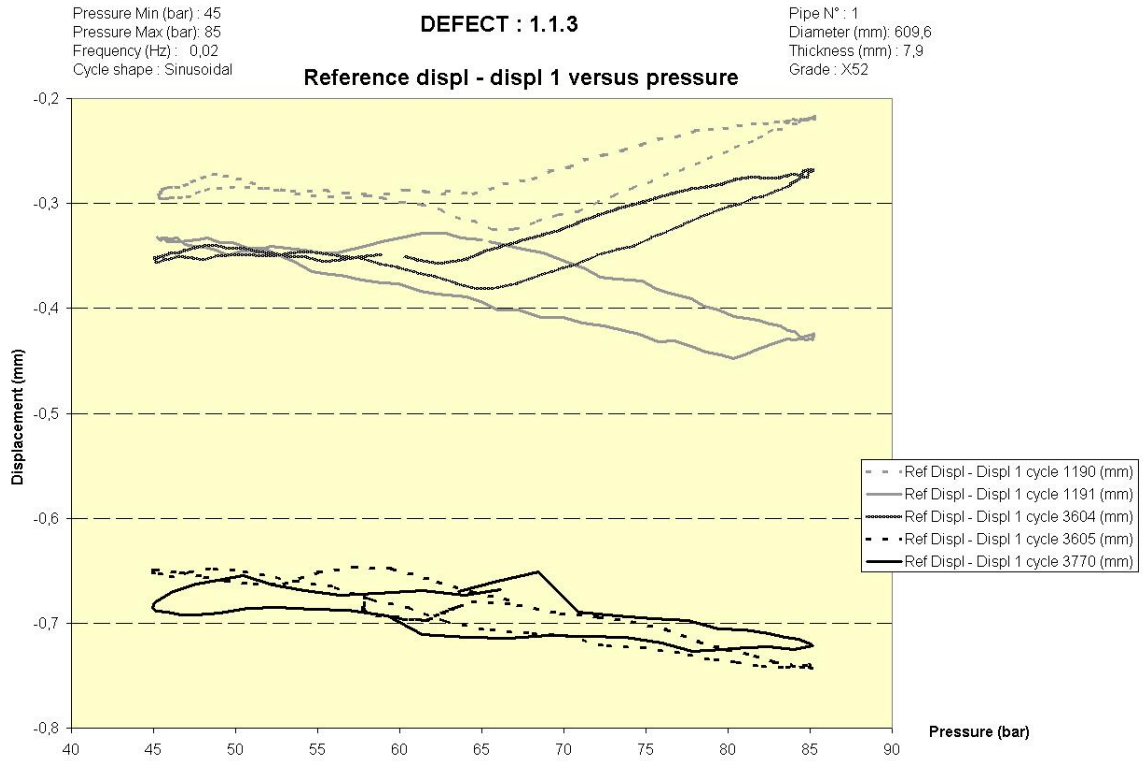

Pressure Min (bar) : 45
Pressure Max (bar): 85
Frequency (Hz) : 0,02
Cycle shape : Sinusoidal
DEFECT : 1.1.3
Reference Displ. - Displ. 2 (mm) versus cycles number
Pipe N° : 1
Diameter (mm): 609,6
Thickness (mm) : 7,9
Grade : X52
Displacement (mm)
Cycles number
Pressure cell failure at cycle 1190
Pressure cell failure at cycle 3604
C1 gage failure at cycle 3770
C1 gage failure at cycle 5383
Potential drop
Displ. 2
Crack
Clip Gauge
Circumferential Strain Gauge
Reference Displacement - Displacement 2 pressure min (mm)
Reference Displacement - Displacement 2 pressure max (mm)

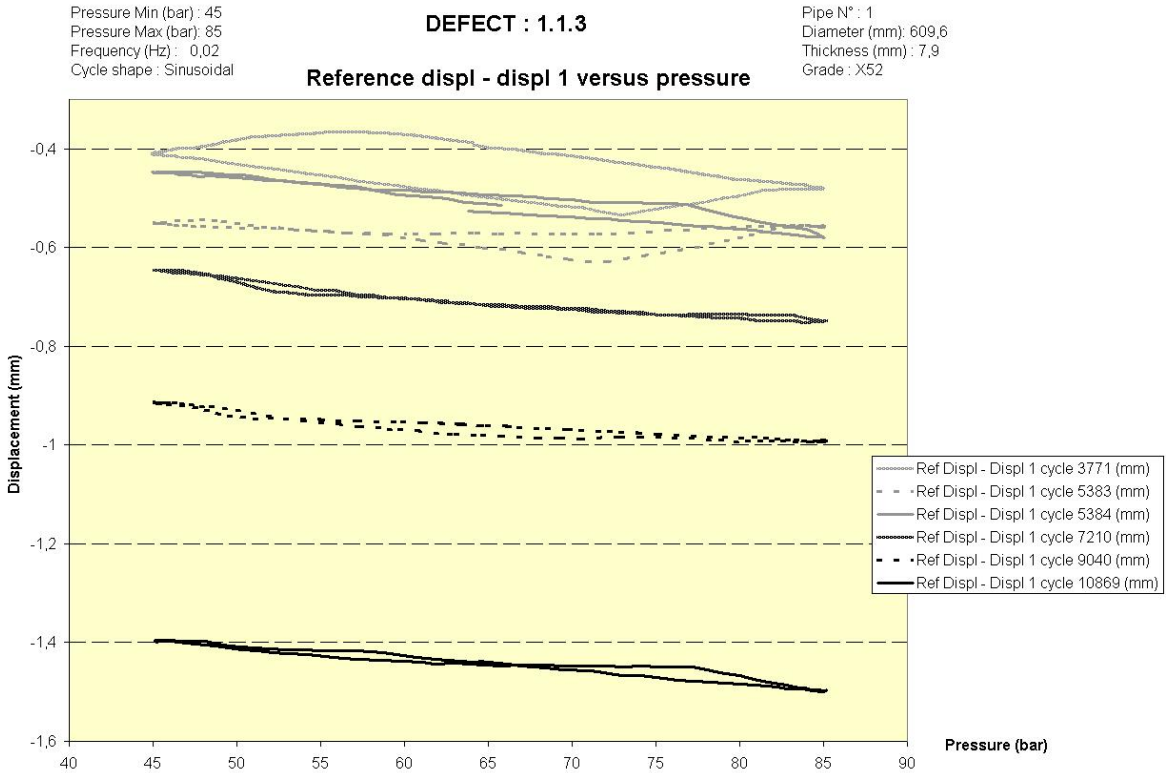
The following curves present information from the clip gage, circumferential gage C1 in the defect, and the difference of the displacements of LVDT1 and LVDT2 for specific cycles, 1190, 1191, 3604, 3605, 3770, 3771, 5383, 7210, 9040 and 10,869. These cycles correspond to particular events (interruption of test or failure of C1 gage) except for the cycles 7210 and 9040, which are mentioned to give a view of the cycles' evolution. For LVDT information, the vertical axis is the difference between LVDT1 or LVDT2 displacements and $LVDT_{reference}$ placed outside of defect on the capacity.

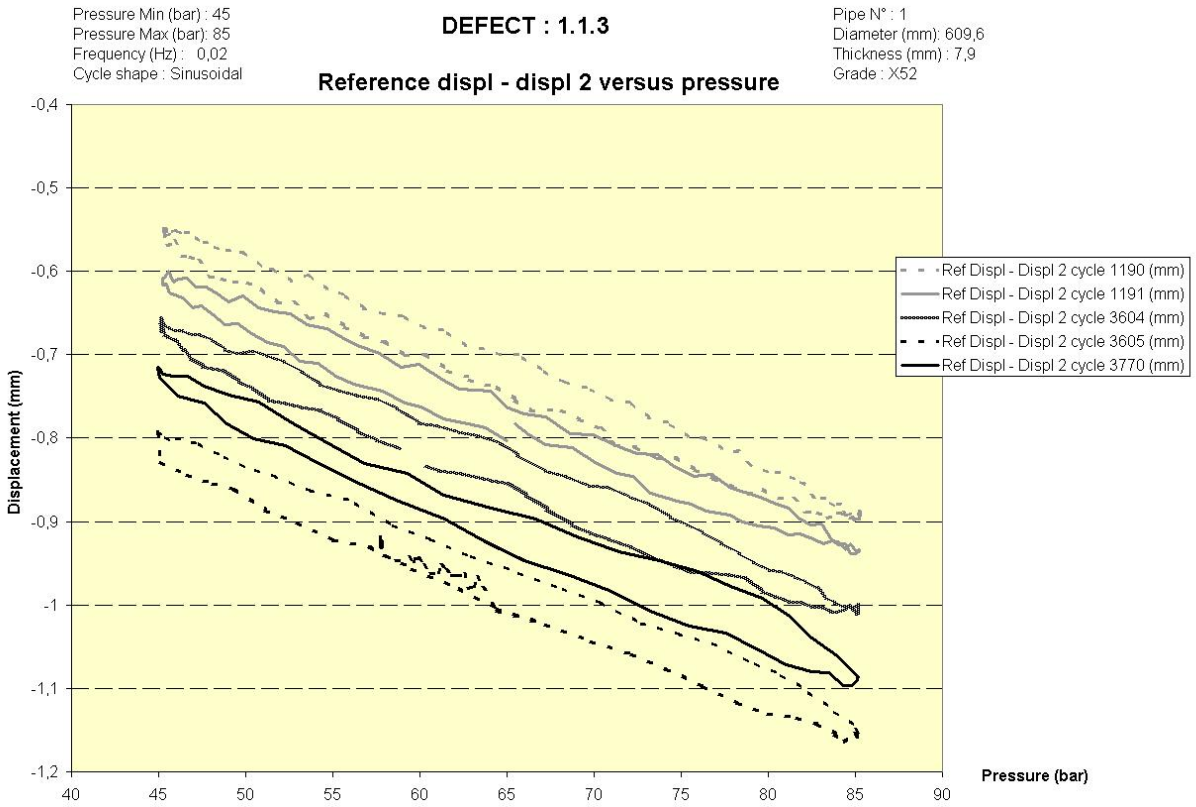


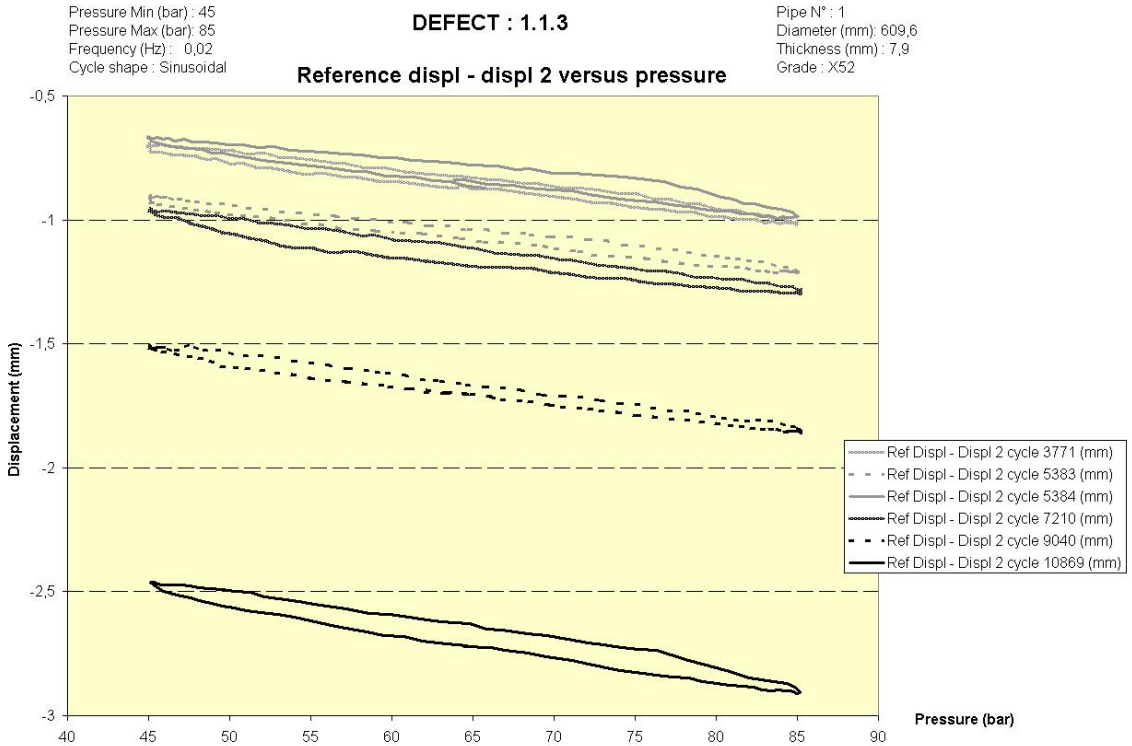

Pressure Min (bar) : 45
Pressure Max (bar): 85
Frequency (Hz) : 0,02
Cycle shape : Sinusoidal
DEFECT : 1.1.3
Clip gage versus pressure
Pipe N° : 1
Diameter (mm): 609,6
Thickness (mm) : 7,9
Grade : X52
Opening (mm)
Pressure (bar)
Clip gage cycle 3771 (mm)
Clip gage cycle 5383 (mm)
Clip gage cycle 7210 (mm)
Clip gage cycle 9040 (mm)
Clip gage cycle 10869 (mm)


Pressure Min (bar) : 45
Pressure Max (bar): 85
Frequency (Hz) : 0,02
Cycle shape : Sinusoidal
DEFECT : 1.1.3
Circumferential gage versus pressure
Pipe N° : 1
Diameter (mm): 609,6
Thickness (mm) : 7,9
Grade : X52
Strain (%)
Pressure (bar)
Circumferential gage cycle 1190 (4%)
Circumferential gage cycle 1191 (4%)
Circumferential gage cycle 3604 (4%)
Circumferential gage cycle 3605 (4%)
Circumferential gage cycle 3663 (4%)

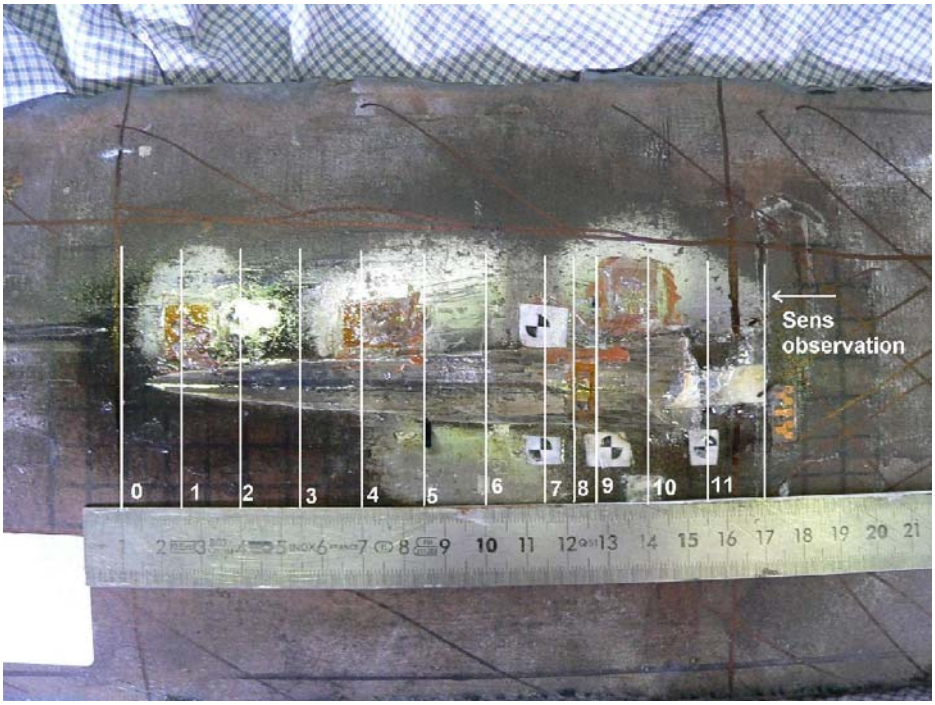

Pressure Min (bar) : 45
Pressure Max (bar): 85
Frequency (Hz) : 0,02
Cycle shape : Sinusoidal
DEFECT : 1.1.3
Reference displ - displ 1 versus pressure
Pipe N° : 1
Diameter (mm): 609,6
Thickness (mm) : 7,9
Grade : X52
Displacement (mm)
Pressure (bar)
Ref Displ - Displ 1 cycle 1190 (mm)
Ref Displ - Displ 1 cycle 1191 (mm)
Ref Displ - Displ 1 cycle 3604 (mm)
Ref Displ - Displ 1 cycle 3605 (mm)
Ref Displ - Displ 1 cycle 3770 (mm)


Pressure Min (bar) : 45
Pressure Max (bar): 85
Frequency (Hz) : 0,02
Cycle shape : Sinusoidal
DEFECT : 1.1.3
Reference displ - displ 1 versus pressure
Pipe N° : 1
Diameter (mm): 609,6
Thickness (mm) : 7,9
Grade : X52
Displacement (mm)
Pressure (bar)
Ref Displ - Displ 1 cycle 3771 (mm)
Ref Displ - Displ 1 cycle 5383 (mm)
Ref Displ - Displ 1 cycle 5384 (mm)
Ref Displ - Displ 1 cycle 7210 (mm)
Ref Displ - Displ 1 cycle 9040 (mm)
Ref Displ - Displ 1 cycle 10869 (mm)

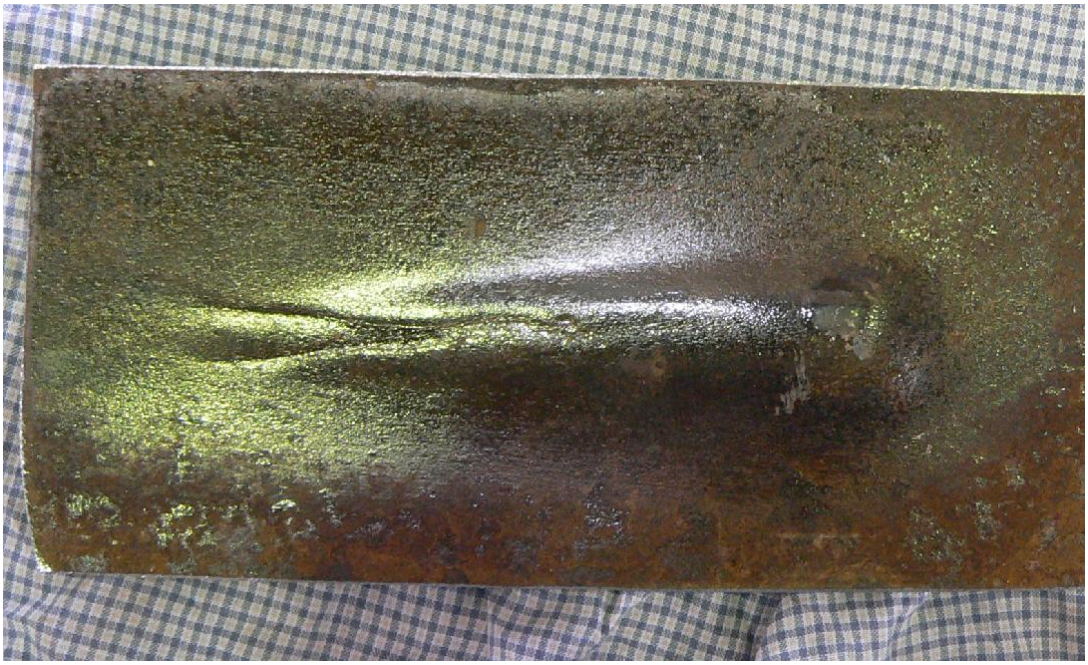

Pressure Min (bar) : 45
Pressure Max (bar): 85
Frequency (Hz) : 0,02
Cycle shape : Sinusoidal
DEFECT : 1.1.3
Reference displ - displ 2 versus pressure
Pipe N° : 1
Diameter (mm): 609,6
Thickness (mm) : 7,9
Grade : X52
Displacement (mm)
Pressure (bar)
Ref Displ - Displ 2 cycle 1190 (mm)
Ref Displ - Displ 2 cycle 1191 (mm)
Ref Displ - Displ 2 cycle 3604 (mm)
Ref Displ - Displ 2 cycle 3605 (mm)
Ref Displ - Displ 2 cycle 3770 (mm)


Pressure Min (bar) : 45
Pressure Max (bar): 85
Frequency (Hz) : 0,02
Cycle shape : Sinusoidal
DEFECT : 1.1.3
Reference displ - displ 2 versus pressure
Pipe N° : 1
Diameter (mm): 609,6
Thickness (mm) : 7,9
Grade : X52
Displacement (mm)
Pressure (bar)
Ref Displ - Displ 2 cycle 3771 (mm)
Ref Displ - Displ 2 cycle 5383 (mm)
Ref Displ - Displ 2 cycle 5384 (mm)
Ref Displ - Displ 2 cycle 7210 (mm)
Ref Displ - Displ 2 cycle 9040 (mm)
Ref Displ - Displ 2 cycle 10869 (mm)

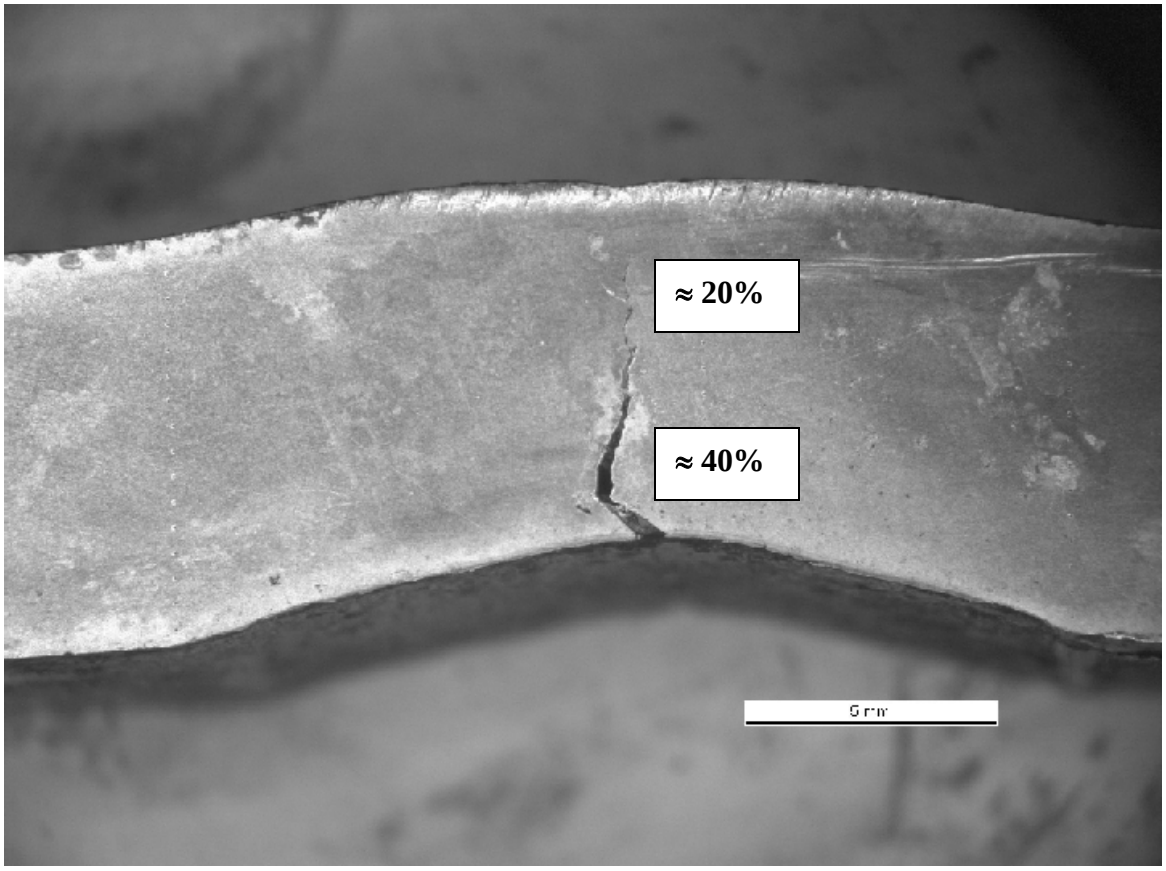
Such as defect 1.1.2, defect 1.1.3 has been cut in ten transverse strip bands after the failure for metallurgical investigation. By using an optical microscope on each cut, a metallurgical observation of microstructure, size of micro-cracks, and rough estimation of strain by micro-hardness calibration under the defect has been done.



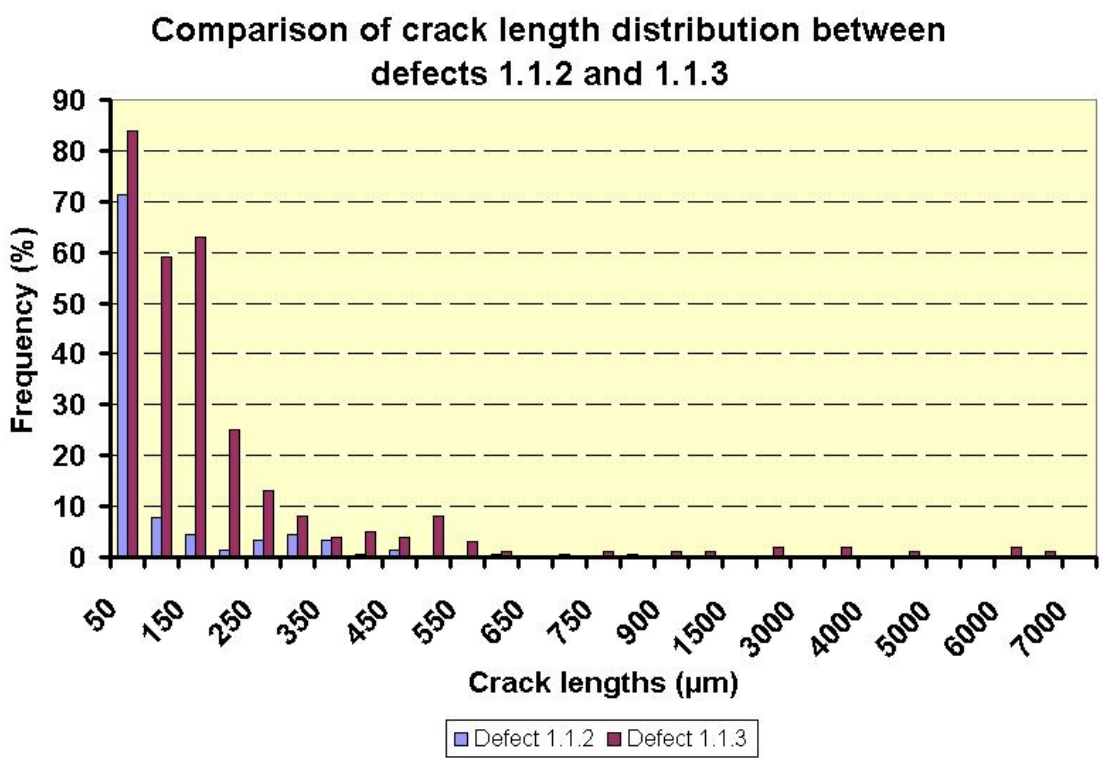
Pipe external view – defect 1.1.3



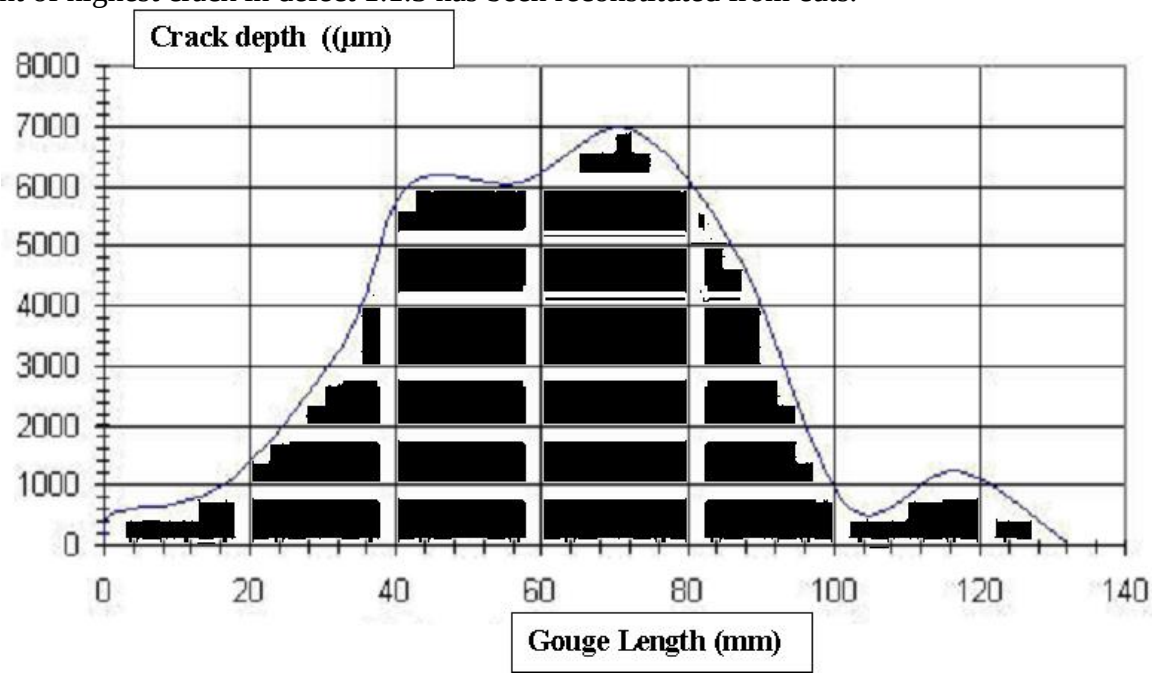
Pipe internal view – defect 1.1.3



Crack propagation on cut 5 and estimation strain from micro-hardness tests



Crack lengths in defect 1.1.3 after the fatigue test are higher than crack lengths in similar defect 1.1.2. Several initial cracks in the defect could propagate during the fatigue test. The propagation front of highest crack in defect 1.1.3 has been reconstituted from cuts.



Shape of propagation front of highest crack in defect 1.1.3 after fatigue failure

Main Conclusions – 31 August 2008:

Creation of defects type:

- Three defects 1.1.1, 1.1.2 and 1.1.3 have been reproduced with a satisfying similarity concerning the length and the dent depth. But a significant difference on gouge depth has been measured between these defects, the depth decreasing from the first defect created (1.1.1) to the last (1.1.2). The defect 1.1.3 was created second. The reason can be explained by the change of the local geometry of the aggressive tooth after the impact; corrective action has been taken to avoid reproducing this phenomenon.
- The defect 1.2.1 is characterized by a deeper dent and gouge but shorter length defect type than defect 1.1.1 ;
- The defect 2.1.1 is the first defect created in material “Pipe 2” characterized by a long defect type with medium dent and gouge depths ;
- In all cases, magnetic powder tests reveal micro-cracks presence at the gouge surface after the defect creation.

Burst test on defect 1.1.2:

- The results of burst testing for the pipe with defect 1.1.2 indicate the pipe failed at a burst pressure corresponding to a pipe without defect. This result can be explained by the high ductility of this material which can fully tolerate a defect type like 1.1.2 under monotonic loads. Nevertheless the change of slope record of different gages and clip gage seem to indicate that the defect started to evolve from a pressure in the range of 60bar-80bar;
- After the burst, defect 1.1.2 was cut for metallurgical investigation. Strain under the defect surface has been estimated around 20% by hardness calibration. A number of

micro-cracks, with 70% below 100 µm length and several around 500µm length have been measured and a crack length distribution has been determined;

- At the surface under the defect, the steel microstructure has been transformed by the heat of the dynamic impact with the aggressivor tooth.

Fatigue test on defect 1.1.3:

- The fatigue test between 45 bar and 85 bar has led to the failure of defect 1.1.3 between 10,480 cycles an 10,869 cycles. Four test interruptions occurred before the failure, two for pressure cell failure and two others to check and/or replace the circumferential gage at the gouge surface;
- At 4247 cycles, the second circumferential gage in gouge was noted to have failed, with confirmation of the failure after the test stopped at 5380 cycles. A crack was observed under the failed gage at 5380 cycles. Several gages present a slope change around 4000 cycles, indicating that crack propagation was likely started around this number of cycles;
- The comparison between potential drop information and clip gage information shows that the clip gage is more sensitive to the defect evolution than the potential drop.
- Such as for defect 1.1.2, defect 1.1.3 has been cut for the first metallurgical investigation after failure. The strain close to the defect surface has been estimated around 40% which is double the strain estimated in the defect 1.1.2, and the crack sizes are deeper than cracks in defect 1.1.2 with a few of them several millimeters long. So, before 10,000 cycles, crack propagations have been initiated from small existing cracks or sharp defects like microscopic scratches or notches after the creation of defect and maybe several cracks have been initiated during the fatigue test.

Business Status

Nothing significant to report.

Schedule & Payable Milestones

The project is currently on schedule per the milestone schedule. We anticipate a delay in Task 2 as discussed above. The delay in procuring the additional steel is not anticipated to have a negative impact on the overall project schedule. Due to the difficulties in procuring the steel, completion of this task will be delayed until May 2009.

Task No.	Task	Status	Scheduled Completion Date	Payable Milestone (Item No)
1	Project Kick Off Meeting and Subcontracting	100% Complete	8/31/2008	1
2	Purchase & Characterize Pipe Material	10% Complete	11/30/2008	2
3	Literature Review	40% Complete	11/30/2008	3
4	Testing of Dents on Welds and Corrosion	5% Complete	11/30/2009	4

	Features			
5	Testing of Dents with Gouges	10% Complete	5/31/2010	5
6	Demonstration of Mech. Damage Model Performance	0% Complete	5/31/2009	
7	Industry Workshop	0% Complete	5/31/2010	
8	Project Management and Reporting	On-Going	5/31/2010	6

Issues, Problems or Challenges

- To improve the similarity between the created defects of the same type, the aggressivor tooth has to be examined after the impact test and potentially retouched/refinished to correct any changes of its initial geometry that may have occurred during creation of earlier defects before beginning the following test and creating the other similar defects.
- For the next defects, 1.2.3 and 2.1.3, a strain gage will be placed in the internal wall of the test pipe in the area where the defect will be created to record strain in the internal wall during defect creation and then during fatigue and/or burst test.
- The residual stresses in defects called x.y.1 are recognized in the same capacity for a given material. This process avoids wasting material by using the same capacity for different x.y.1 defects in the same material in place of attributing one capacity per defect. The consequence is that the residual stress determination and the metallurgical characterization of these created defects will be realized at the end of the last created defect type for a given material (Pipe 1, Pipe 2, Pipe 3, Pipe 4).

Plans for Future Activity

Planned activities for the project are presented below.

Task 2: Purchase & Characterize Pipe Material

- Achieve the tests on pre-strain effect on toughness for pipe 1 material;
- Launch of material characterization on pipe 2.

Efforts to complete the pipe procurement will continue with a desire to confirm the source of the steel in the next quarter.

Task 3: Literature Review

The information on pre-strain effect on toughness and on realistic defects determined in the field will be monitored by attending or reviewing information from new conferences, workshops and results of projects from various consortiums.

Task 4: Testing of Dents on Welds and Corrosion Features

Full scale testing of the plain dents in the test matrix will be completed with a start planned for the dents on corrosion features.

Task 5: Testing of Dents with Gouges

- Supplementary interpretation of burst test on 1.1.2 defect burst test and fatigue test on 1.1.3 defect;
- Results of defect creations for 1.2.2 and 2.2.2 defects;
- Burst tests on 1.2.2 and 2.2.2 defects;
- Preparation and instrumentation for 1.2.3 and 2.1.3 defects with a variant consisting to place gage in internal wall before the creation of defect;
- Creation of 1.2.3 and 2.1.3 defects;
- Proposal for the last type of defect 1.3.1 for Pipe 1.

APPENDIX A

Notes Recorded During Project Kick-off Meeting with PHMSA
Structural Significance of Mechanical Damage – DOT/PHMSA Project #238
DTPH56-08-T-000011

DOT Western Regional Office - Denver, CO
July 11, 2008

Project Team review of slide presentation files

- MD 4-1
    - covers re-rounding through instrumentation set up for fatigue test
    - proposed addition of internal strain gauge based on initial results
- MD 4-2
    - Discussed material purchase/selection and characterization – manufactured vs. former in-service pipeline, pros and cons
    - dent depths show depth prior to indenter removal
    - corrosion is represented as wall thinning

- PRCI to distribute the data request for vintage pipe to membership while evaluations for potential manufacturing options continue

- Need to address database management; multi-media data management. What will and will not be included in the database that will be made public and widely available. Relevant, higher level data to be included. Additional details (underlying measurements and spreadsheet/access database records) to be provided on request, as appropriate.

- Progress updates – calls with Jim Merritt after submitting quarterly report

- Task 7 - Knowledge based product is outcome of project – workshop is best venue
    - Research Exchange 2010 – report out to industry on findings to date
    - IPC 2010 – Paper from team on project results, key findings, etc.
    - Consensus from workshop may drive future work on this topic

- Reviewed the chart prepared for the meeting that addressed project risks/challenges; the Technical Committee agreed that the chart should be maintained and updated on a routine basis and reviewed during each meeting as an effective approach to addressing potential project problem areas.

- Jim Merritt requested critical design review with the Project Technical Committee at key points in projects. These reviews would include discussion of several key decision points:
    - Is there sufficient data to represent the various characteristics of defects encountered by operators?
    - Has the testing program covered all of the relevant materials of construction, vintage and higher strength more modern steels
    - Increasing x-ray inspection of welds

- Increasing instrumentation to include all defects rather than the current proposed 50%

Action Items

- Post slides from meeting to web site
- Team to contact Battelle on guidance for more detailed video documentation of fatigue tests
- Check DOT database on failure incidents – DOT to provide additional details that may not be included in the public databases that are important to the study (i.e., any material characteristics or other notes recorded)
- Evaluate whether a contract modification is necessary after initial data collection to expand the program for x-ray inspection and instrumentation for testing program
- Revise Project Risks table/chart based on input from the meeting and re-issue to PHMSA. The chart will be maintained and referenced during project meetings as a living document and iterative record of project pressure points. Current chart is presented below.

Identified Risks

Risk Item	Techincal Risk	Schedule Risk	Budget Risk	Mitigation Plan	Consequence
Exchange Rate			X	None	Project is underfunded for completion.
Tested materials not representative of high risk materials in the field	X		X	Seek out vintage pipe to complement moderm pipe already being tested	Project will develop test results that do not consider the range of material toughnesses in operation, on low side
Testing does not produce a sufficiently wide range of results for full model validation (e.g. indenter shape and size and number of dent peaks)	X		X	Plan test program variables to consider a logical and wide range of conditions. Use data developed to validate numerical models to explore other geometries. Could also expand test matrix, but need to resource this extension.	Validation base for assessment model may be too narrow.
Vintage pipe used in testing is witdrawn from service	X	X	X	Early action in defining pipe requirements and sources. Need to consider additional material testing and budget resources to support this.	Uncertainty in test results due to variability in material properties, pipe condition. Delay in project if pipe is not available from dig programs.
Weld metal material properties not characterized	X		X	Must complete additional material testing on weld metal to define welment properties. This extension to test matrix needs to be resourced	Future refined mechanistic model development will be short of data for characterization.
Not all samples are instrumented and an interesting behaviour may be missed if it occurs in a non-instrumented sample	X		X	Set instrumentation plan to cover at least one of each dent geometry. Instrument all samples. This extension to test matrix needs to be resourced	Uncertainty in test results
Varaibility in fatigue performance not captured due to too few repetitions of a given scenario	X		X	Increase the number of test sample repetitions. This extension to test matrix needs to be resourced	Uncertainty in test results
Welds may contain defects. While procedure will be API 1104 certified and 6 specimens will be inspected other welds may include defects	X		X	Complete 100% weld inspection. This extension to test matrix needs to be resourced	Uncertainty in tests results
Additional measurements are required by modelling activities: e.g. Dent& Gouge: additional strain gauges on pipe inside beneath damage	X		X	Keep strong communication with modelling teams, to foster thier implication in specification of measurements & immediate application of results, and identify possible additional requests. These need additional funding	Less complete data set
Testing runs slower than expected		X		Either lengthen project schedule or add additional testing facility. The additional testing facility will require additional project funds	Delay in data production