QUARTERLY REPORT

Project WP#339: Structural Significance of Mechanical Damage

For Period Ending: August 31, 2009

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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PRCI LEADING PIPELINE RESEARCH

Milestone and Deliverable Accomplishments this Reporting Period

Task No.	Task	Scheduled Completion Date	Completed Date	Milestone
2	Purchase & Characterize Pipe Material	Estimated 09/30/2009	Ongoing	
3	Literature Review	06/30/3009	Ongoing	MS
4	Testing of Dents on Welds and Corrosion Features	08/30/2009	Ongoing	MS
5	Testing of Dents with Gouges	5/31/2010	Ongoing	MS
6	Demonstration of Mech. Damage Model Performance	11/30/2009	Not Yet Started	MS
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 fourth quarter focused on the following tasks:

- Task 2: Purchase & Characterize Pipe Material
- 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 to date are presented below for each tasks.

The technical group for this program has maintained close communication to ensure program coordination. Issues of concern in the program have been forwarded to PRCI and DOT for their consideration.

Task 2: Purchase & Characterize Pipe Material

Technical Status
The entire program comprises 3 different pipe steels:

- Pipe 1 and 2 are two modern IPSCO pipes manufactured between 2005 and 2006

- Pipe 3 is planned to be older steel, either a former operating/in-service vintage pipe from one of PRCI's member companies or a manufactured pipe that replicates vintage pipe properties. The team is still establishing the source of Pipe 3.

A potential source has been identified to manufacture Pipe 3 which will represent the older/vintage pipes. The potential source will create the material with properties replicating the observed lower toughness found in the 1950's or 1960's era pipelines. The technical group for the project is evaluating the cost, schedule, and benefits of a manufactured option which would avoid the variability introduced by unknown operations (i.e., pressure cycling over time) and is

coordinating the final decision with PHMSA. The funding for the purchase of the material is to be finalized.

GDF SUEZ has received three samples of Pipe 1 and two samples of Pipe 2 all of 11.8 meters in length. Pipe 1 is API X52 grade and has a 24 in. diameter and 7.9 wall thickness. Pipe 2 is API X70 grade. It also has a 24 in. diameter but has a wall thickness of 9.0 mm. The pipes were manufactured by IPSCO with the ERW process.

In the previous quarterly reports, GDF SUEZ presented material characterization results for Pipes 1 and 2:

- Tensile properties in longitudinal and transverse directions;
- Charpy V impact values in different directions at room temperature;
- Toughness J Curve;
- Pre-strain effects on toughness for pipe 1
- Size of slip bands (Extra-work)

In the 5th Quarterly period, the measurement of the effect of pre-strain on toughness was launched for Pipe 2.

Task 3: Literature Review

Technical Status

The literature review regarding cyclic fatigue dent assessment techniques is still ongoing. A report summarizing the review and selected techniques will be completed in the coming quarter.

Task 4: Testing of Dents on Welds and Corrosion Features

Technical Status

The testing of the dents interacting with girth welds is ongoing with approximately 8 specimens still to be tested. Issues related to failures outside of the dent region have delayed the testing program, however the remaining specimens should result in failures in the dent region, precluding the need for further repairs.

	Pipe	Indenter	Initial Dent	Dent	Interacting	Initial Pressure	Second Pressure	Cyclic Pressure	Weld Seam
Specimen #		Diameter	Depth	Condition	with	Cycle	Cycle	Range	Location
		(in)	(%)			(%SMYS)	(%SMYS)	(%SMYS)	
21	1	2	5	R	Girth Weld	100%	80%	10%-80%	Shoulder
22	1	2	5	R	Girth Weld	100%	80%	10%-80%	Shoulder
23	2	4	10	R	Girth Weld	100%	80%	10%-80%	Shoulder
24	2	4	10	R	Girth Weld	100%	80%	10%-80%	Shoulder
25	1	2	15	U	Girth Weld	100%	80%	10%-80%	C.L.
26	1	2	15	U	Girth Weld	100%	80%	10%-80%	C.L.
27	1	2	15	U	Girth Weld	100%	80%	10%-80%	Shoulder

28	1	2	15	U	Girth Weld	100%	80%	10%-80%	Shoulder
29	1	4	15	U	Girth Weld	100%	80%	10%-80%	Shoulder
30	1	4	15	U	Girth Weld	100%	80%	10%-80%	Shoulder
31	2	2	15	U	Girth Weld	100%	80%	10%-80%	Shoulder
32	2	2	15	U	Girth Weld	100%	80%	10%-80%	Shoulder
33	2	4	15	U	Girth Weld	100%	80%	10%-80%	Shoulder
34	2	4	15	U	Girth Weld	100%	80%	10%-80%	Shoulder
35	2	4	15	U	Girth Weld	100%	80%	10%-80%	C.L.
36	2	4	15	U	Girth Weld	100%	80%	10%-80%	C.L.

Development of the detailed test matrix for the dents on corrosion features, including the size, shape, and location of the simulated corrosion features is currently ongoing. A finalized test matrix will be provided to the technical group for feedback prior to starting the testing.

Task 5: Testing of Dents with Gouges

Technical Status

GDF SUEZ is in charge of the creation, characterization, burst test and fatigue test of realistic combined defects, i.e., "dents with gouges", following the program described in the next table:

The defects are identified by three characters **X.Y.Z.** which are numbers:

- **X.**Y.Z.: **X** identifies the **Pipe X** material which is noted by 1, 2, or 3 in this program;

- X.**Y.**Z.: **Y** defines the **type of dent and gouge defect** characterized by its geometry notably in terms of dent depth and length, and gouge depth and length. This program is considering a maximum of three different kinds of defects per pipe material, and therefore, the value of Y can range from 1 to 3;

- X.Y.**Z.**: **Z** is the **number of defect in the defined type of defect**. There are three similar defects per type of defect. The number 1 is for a detailed geometrical, mechanical and metallurgical in-depth defect characterization after its creation. Number 2 is a similar defect for the burst test to evaluate the defect behavior of under monotonic pressure load and number 3 is a similar defect for the fatigue test to evaluate the defect behavior under cyclic variation of the internal pressure.

In the previous quarterly reports, the following results were presented:

- Creation conditions and results for 11 defects (9 + 2 repeated ones): 1.1.1, 1.1.1b, 1.1.2, 1.1.3, 1.2.1, 1.2.1b, 1.2.2, 1.2.3, 2.1.1, 2.1.2 and 2.1.3
- Burst test conditions and results for 2 defects in pipe 1, 1.1.2, 1.2.2 and one in pipe 2: 2.1.2
- Fatigue test conditions and results for 2 defects in pipe 1: 1.1.3, 1.2.3
- Metallurgical Failure Investigation for 3 defects: 1.1.2, 1.1.3 and 1.2.2.

This report presents:

- Defect creation and characterization of defect 1.3.2,
- Fractographic investigation of fatigue failure for defect 1.2.3,
- Surface residual stresses of defect 2.1.1.

The table below summarizes the progress of the task on "Dent and Gouge" defects since the beginning. The background color in the table represents:

- White: Defects not yet created
- Yellow: Defects already created but not yet metallurgically investigated or submitted to either Burst or Fatigue tests
- Green: Defects created and tests completed

Results and Conclusions

Task 2: Material Characterization – Pre-strain effect on toughness of pipe 2

The measurements of the effect of pre-strain effect on toughness of pipe 2 are underway. Pipe steel bars were pre-strained up to 5% and 10% strains. SENB specimens were machined from these bars for J-Curve tests. Results are expected for October 2009.

Task 5: Testing dents with gouges: Creation and characterization of defect 1.3.2.

A new type of Dent + Gouge defect was created following the advice from the project team. This defect has a deep dent and a shallow gouge created with a slower aggression, as opposed to previous defects which were characterized by a shallow dent and a deep gouge. Figure 1 shows a photo of this defect. The defect was created under an internal pressure of 30 bar (load factor of 26% of actual yield strength) to favor a deeper dent.

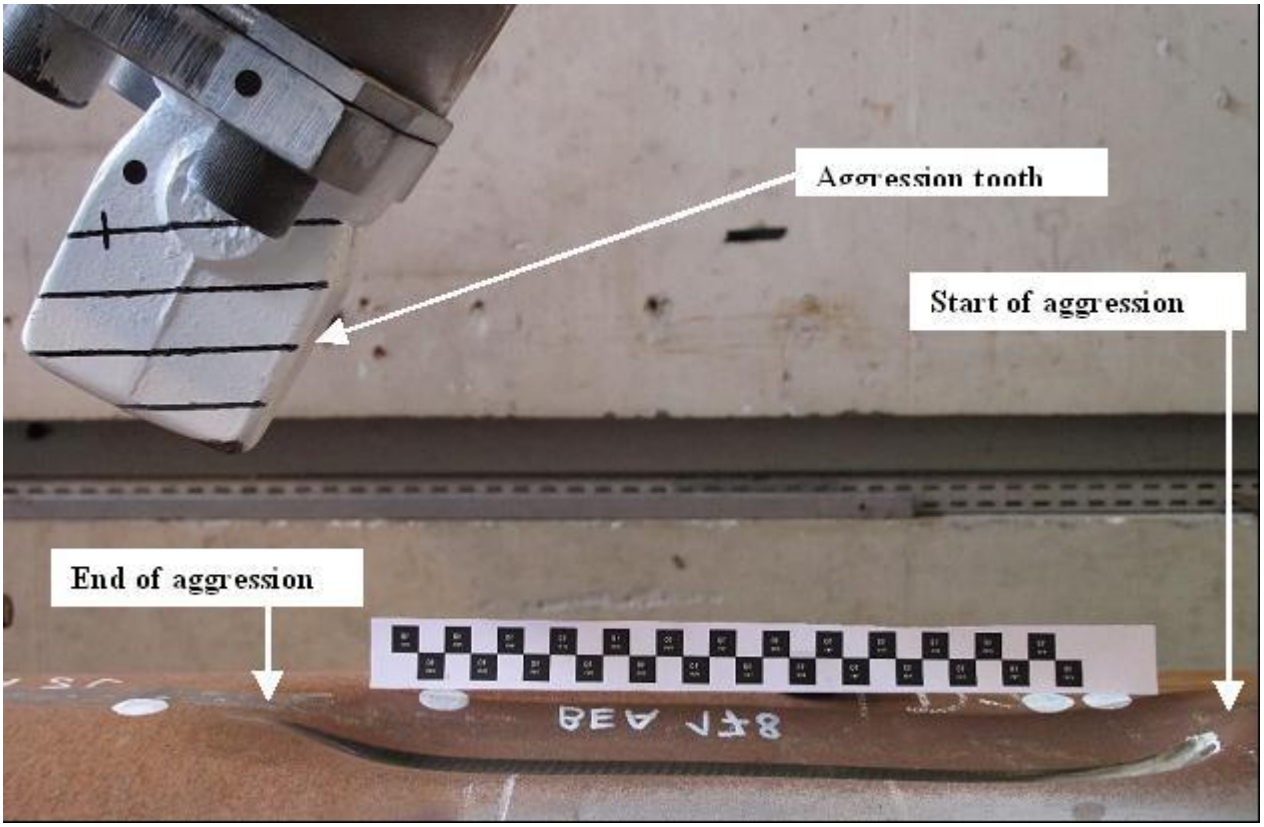

Figure 1: Defect 1.3.2 and aggression tooth

Defect 1.3.2. is more than 300mm long and the residual dent depth (pressure = 0) is larger than 5%. Unlike previous defects created under highly dynamic conditions, magnetic powder inspection (MPI) did not reveal the presence of cracks or micro-cracks at the bottom of the gouge (Figure 2).

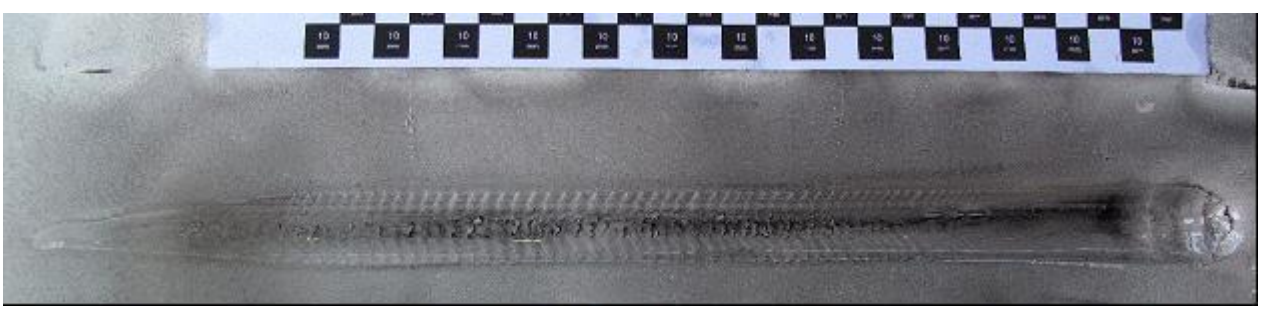

Figure 2: Defect 1.3.2 - No crack or micro-crack revealed by magnetic powder inspection

Two-dimensional profiles in transverse and longitudinal pipe directions passing by the deepest point of defect 1.3.2 are presented in Figures 3 and 4. The maximum residual dent depth (with internal pressure = 0) is 5.3%.

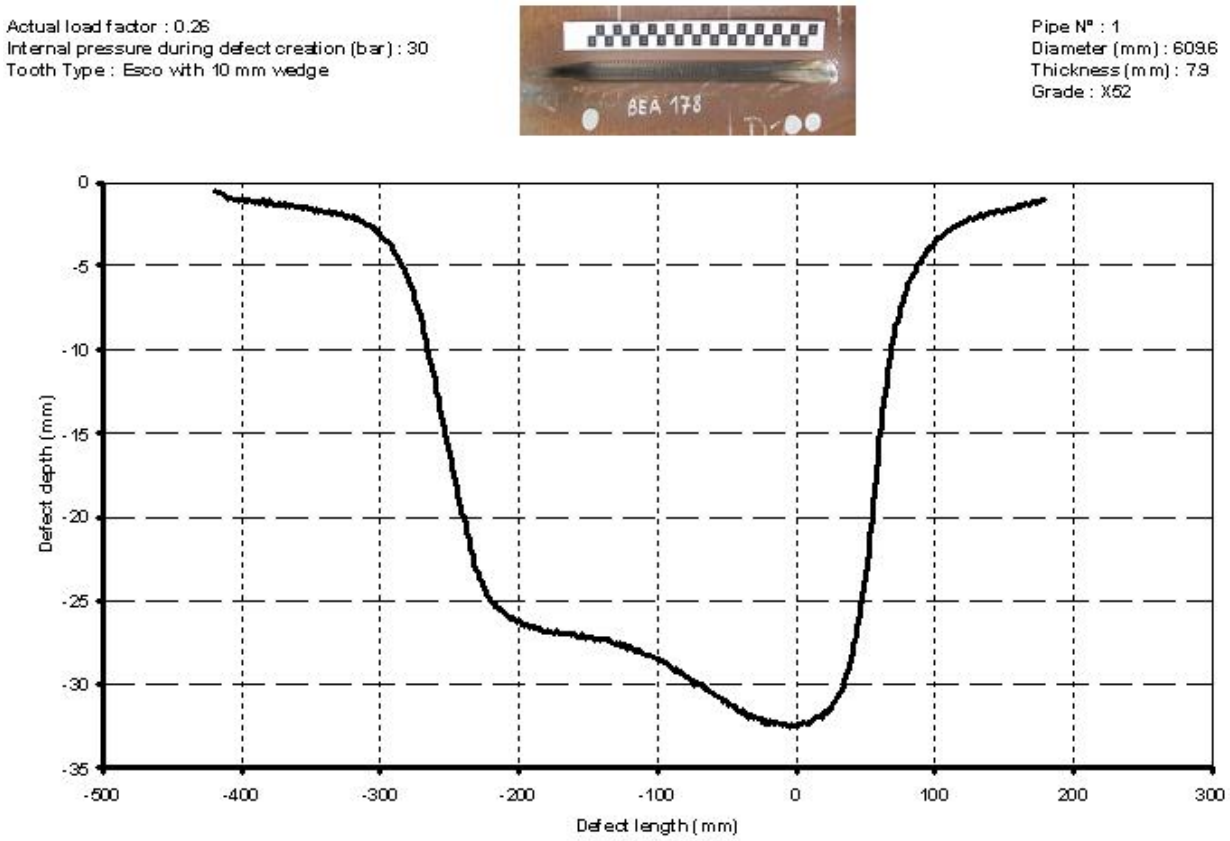

Figure 3 : Defect 1.3.2 – 2D Longitudinal Profile

Actual load factor : 0.26
Internal pressure during defect creation (bar) : 30
Tooth Type : Esco with 10 mm wedge

Pipe N° : 1
Diameter (mm) : 609.6
Thickness (mm) : 7.9
Grade : X52

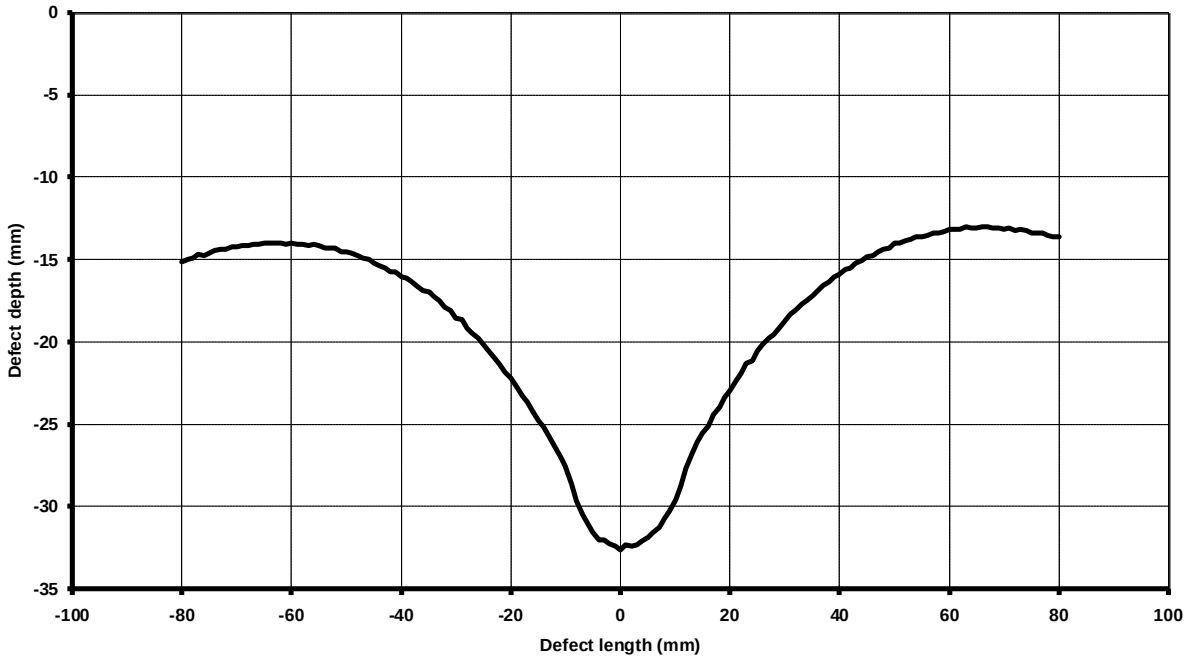

Figure 4 : Defect 1.3.2 – 2D Transverse Profile

Task 5: Testing dents with gouges: Fatigue Failure Investigation of defect 1.2.3

Defect 1.2.3 failed by leak after about 4,300 cycles of internal pressure between 45-85 bar. After failure, the defect was cut into 10 samples for metallographic investigation (Figure 5)

Figure 5 : Defect 1.2.3 cut in 10 samples for metallographic investigation

Figure 6 shows a transverse view of cut number 7

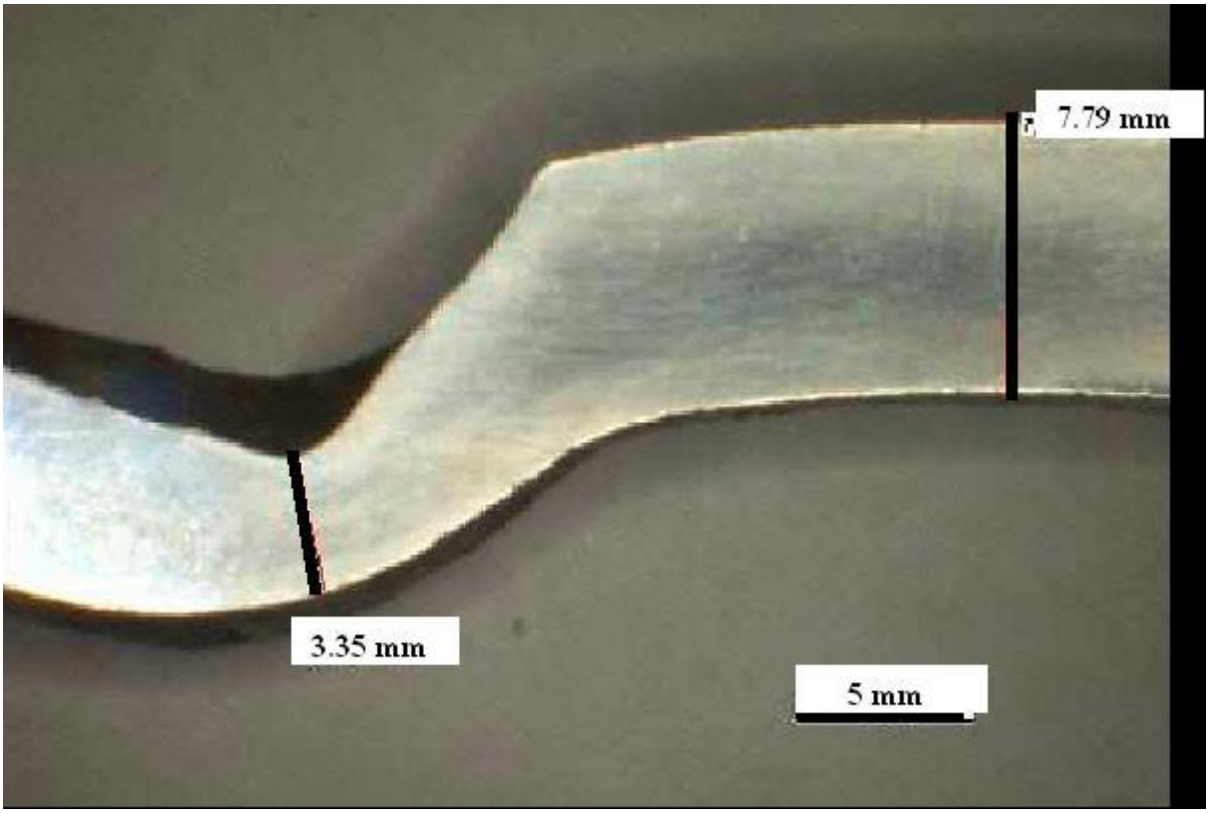

Figure 6: Transversal cut number 7

In Figure 6 the minimum thickness in the gouged and thinned section is approximately 3.35 mm whereas the pipe thickness is about 7.79 mm. During defect creation, the combination of steel removal and thinning due to denting resulted in a reduction of 57% of pipe thickness under the gouge (remaining ligament thickness of 43%). Optical microscopy examination showed several micro-cracks with depths up to 500µm and the main fatigue crack were observed at the defect surface (Figures 7 and 8). A hardened layer of about 10 µm thickness covers the external surface of the gouge. Certain cracks are contained only in this layer and other start in this layer and continue farther into the pipe. The team supposes that the micro-cracks confined in the hardened layer are initiated during the defect creation. In contrast, the cracks that prolong beyond the hardened layer also originated in the hardened layer during the defect creation and propagated during the fatigue loading.

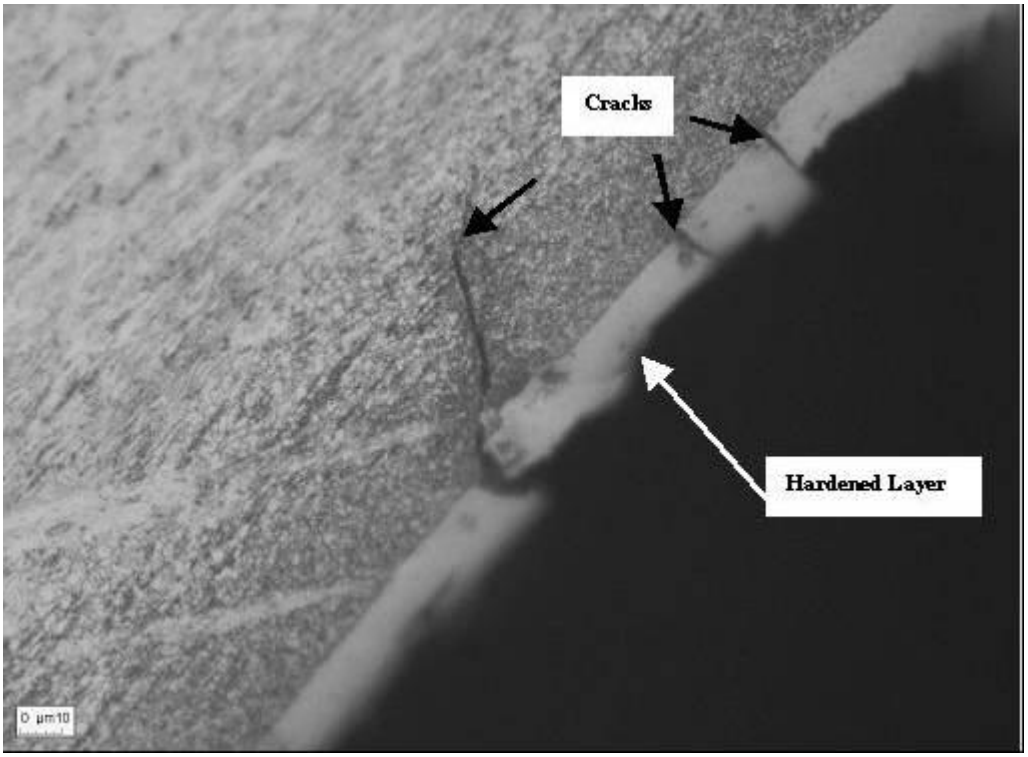

Figure 7 : Cracks at the external defect surface.

Figure 8 : Crack propagation from external surface of defect.

Figure 9 shows that the grains are extremely stretched and a network of micro-cracks sometimes seem to follow the grain joints.

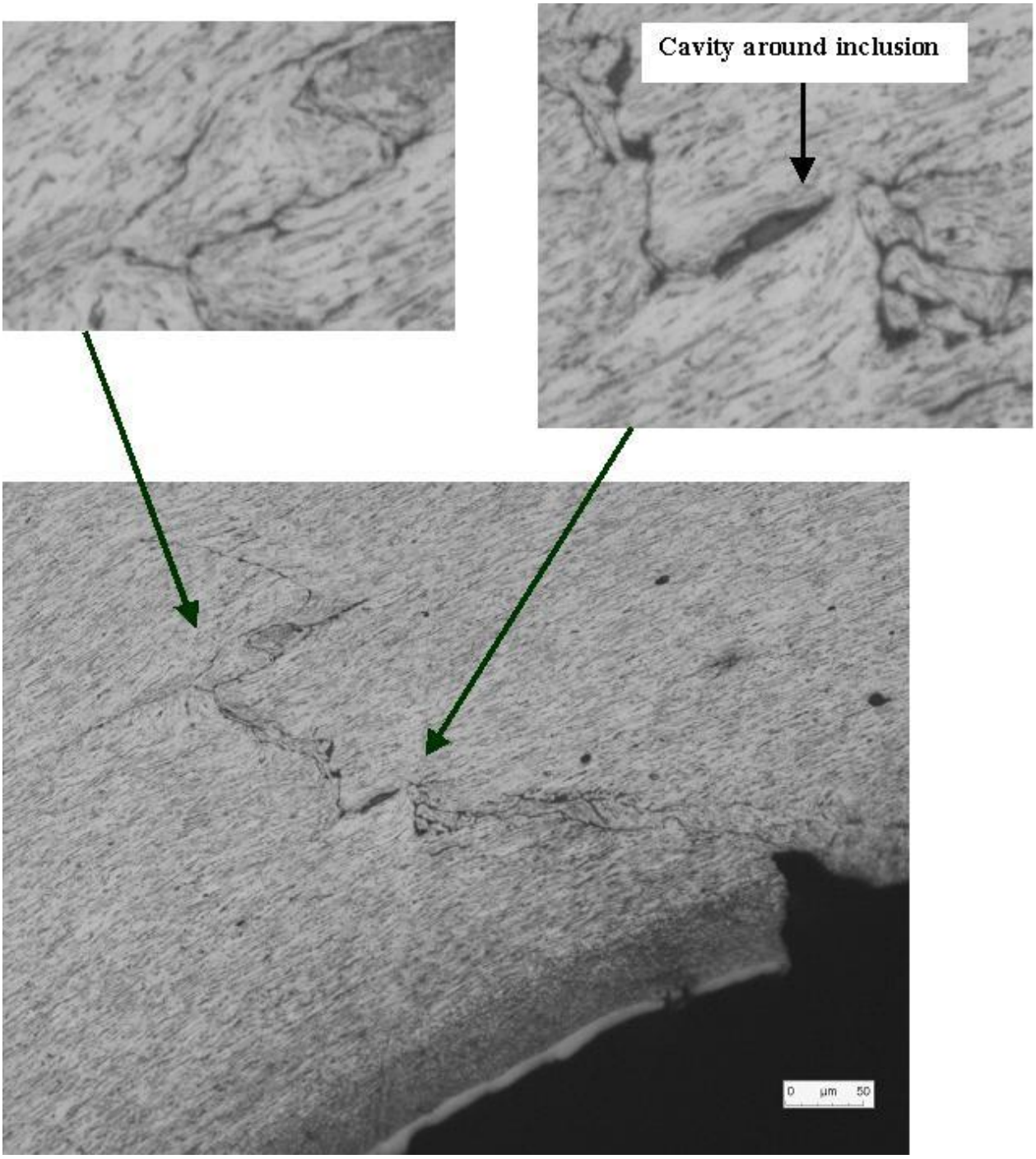

Figure 9 : micro-cracks network through stretched grains and inclusions

Locally, micro-hardness measurements in the damaged zone roughly estimates strains up to 60%.

Task 5: Surface residual stresses of defect 2.1.1

The team used the x-ray method to determine residual stresses on the internal and external pipe surfaces of defect 2.1.1. The team measured residual stresses on the external surface in both directions (hoop and axial). On the internal surface, they only measured residual stresses in the hoop direction. Figure 10 shows the results with the following color code:

- Blue: Axial residual stress on the external surface;
- Red: Hoop residual stress on the external surface;
- Green: Hoop residual stress on the internal surface.

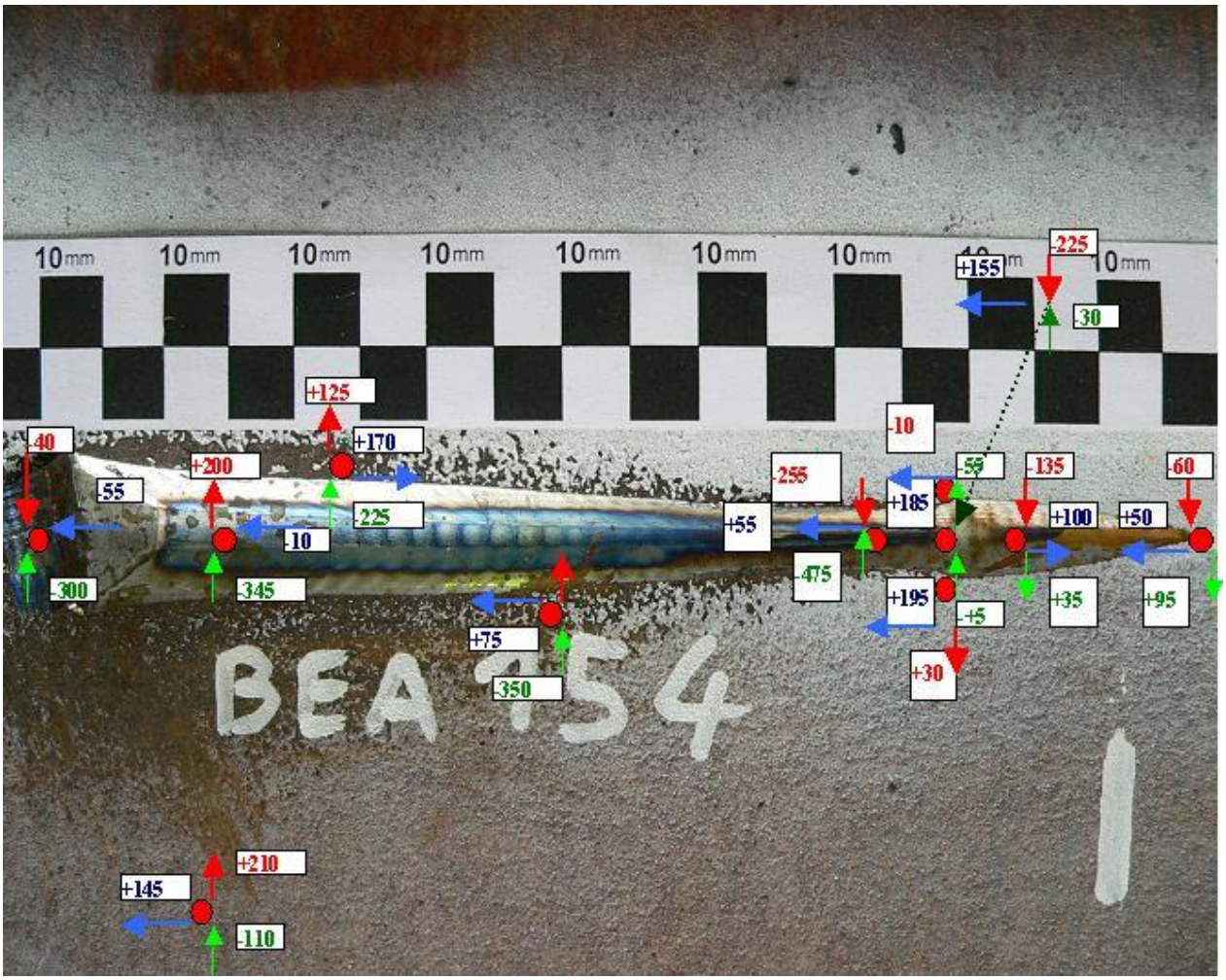

Figure 10: Surface residual stresses for defect 2.1.1

The residual stresses varies considerably from one location to another :

- **Hoop residual stresses** on the **external surface** (red color) are in compression at the aggression start and in tension at the end. The stress level ranges from -225 MPa, to +210 MPa];

- All **axial residual stresses** on the **external surface** (blue color) are in tension at the aggression start with stress levels up to +195MPa. They have low tensile or compressive values in the middle and at the aggression end;

- **Hoop residual stresses** on the **internal surface** (green color) are slightly in tension at the very aggression beginning and in severe compression beyond that area with a high maximum stress level of –475MPa.

Residual stresses were also measured in one location at 40 mm from the defect and the stress levels were still significant (maximum –110MPa and +210MPa in hoop direction on the internal and external surfaces, respectively. The stress levels were measured at +145MPa in axial direction on the external surface).

Main Conclusions:

Task 5: Testing Dents with Gouges : Creation and characterization of defect 1.3.2.

The defect 1.3.2 was created with a low internal pressure (30 bar) to favor a shallow gouge and a deep dent. A different, rounded tip excavator tooth was used with a slow aggression speed. The defect length is about 300mm with a residual dent of 5.3% (internal pressure=0). This type of defect is very different from previous defect types which were characterized by a severe gouge and shallow dent and high impact velocity. The team did no find any surface cracking or micro-cracking using by magnetic powder inspection (MPI).

Task 5: Testing Dents with Gouges : Fatigue Failure Investigation of defect 1.2.3

Samples of the dent and gouge were cut after failure to observe steel damage and deformation in the reduced thickness under the defect. Using optical microscopy, the team found that the steel grains were extremely stretched and roughly estimated a 60% strain through micro-hardness measurements. As for other high velocity impact defects, a 10µm thick hardened layer was found at the external defect surface indicating that high temperature was reached by contact with the tooth during the dynamic defect creation. Several cracks and micro-cracks start from the hardened layer at the external surface and travel into the pipe at a depth of up to 0.5mm. Some of them remain in the hardened layer, whereas other propagate into the pipe. In other cases, there is a network of micro-cracks propagating around stretched grains and joining the damaged inclusion.

Task 5:Testing Dents with Gouges : Surface residual stresses of defect 2.1.1.

Residual stresses were found on the internal and external surfaces of defect 2.1.1. Hoop residual stresses are in tension and compression on the external surface, and in compression with locally very high values on the internal surface. Axial residual stresses are in tension on the external surface.

Business Status

The project remains well coordinated with the pipeline industry through the PRCI partnership on the project. Please refer to Attachment 1 for a summary of the resource status of this program. This attachment includes a quarterly accounting (broken out by Project milestones) of budgeted, current and cumulative expenditures, including cost share amounts. The attachment also explains any major deviations and discusses the adjustment actions proposed.

Schedule & Payable Milestones

Task No.	Task	Status	Scheduled Completion Date	Payable Milestone (Item No)
1	Project Kick Off Meeting and Subcontracting	100% Complete	8/31/2008	
2	Purchase & Characterize Pipe Material	80% Complete	11/30/2008	
3	Literature Review – effect of pre-strain and dent-gouge defect from field feed-back	100% Complete	11/30/2008	
4	Testing of Dents on Welds and Corrosion Features	65% Complete	11/30/2009	16
5	Testing of Dents with Gouges	70 % Complete	5/31/2010	17
6	Demonstration of Mech. Damage Model Performance	0% Complete	5/31/2010	
7	Industry Workshop	0% Complete	5/31/2010	
8	Project Management and Reporting	On-Going	5/31/2010	19

Issues, Problems or Challenges

- Task 2 is slightly behind schedule due to identifying pipe and collecting cost/schedule data for the vintage pipe. Neither task will delay the overall schedule of the project if a satisfactory solution is identified for pipe delivery.

- The residual stresses in defects called x.x.1 are measured on the same vessel for a given material. This process avoids wasting material by using the same vessel for different x.y.1 defects. The consequence is that the residual stress measurements and the metallurgical characterization of these already created defects will be performed at the end of the defect creation process for a given material (Pipe 1, Pipe 2, or Pipe 3).
- A failure of the automated pressure pump used to cycle the internal pressure for the dent and girth weld specimens experienced a failure and required repair. Repair was carried out and testing restarted on the remaining girth weld specimens.
- NDI inspection of the fabricated girth welds revealed several specimens that had rejectable weld faults. The specimens, their faults and the resulting repairs and re-inspection have all been documented for reporting purposes. The complete girth weld

procedure, including edge preparation has been reviewed and revised in order to avoid repairs in the future.

- Testing of the restrained dents interacting with girth welds resulted in leaks initially forming outside of the dent region, along the circumference of the pipe at the girth weld. These have been repaired and testing is continuing. The initial failures for the unrestrained dents occur in the dent region so there is no need for repairs to these specimens. All the remaining girth weld specimens to be tested are unrestrained so no further repairs are expected.
- The expected completion date for the testing of plain dents and dents interacting with girth welds and simulated corrosion features cannot currently be met due to the delay in procuring of the third pipe material (Pipe C). A revised completion date cannot be estimated prior to placing an order for Pipe C.

Plans for Future Activity

Planned activities for the project are presented below.

Task 2: Purchase & Characterize Pipe Material

Team is preparing a summary plan outlining the steel procurement justification and cost analysis. Results on pre-strain effect on toughness of pipe 2 material will be completed.

Task 3: Literature Review

A report summarizing the findings of the literature review of the cyclic fatigue dent assessment techniques will be completed and delivered in the next quarter.

Task 4: Testing of Dents on Welds and Corrosion Features

Full scale testing of dents on welds is ongoing with a scheduled completion date of 10/15/2009. A detailed test matrix summarizing the details of the dents on corrosion features will be completed and provided for review in the next quarter.

Task 5: Testing of Dents with Gouges

Provide detailed fatigue test results for defect 2.1.3. Launch the creation of defect 2.2.2. Perform burst tests of defects 1.3.2 and 2.2.2.

Prepare complete reports for the PRCI project for the tests done so far. The format for reporting will be agreed upon with the project team before finalization.

Attachment 1: Business Status Section

Technical and Deliverable Milestone Schedule							
Item No.	Task No. (per proposal)	Quarter No.	Expected Completion Date/Mos	DOT to GDF SUEZ	PRCI Cash Cost Share to GDF SUEZ	Progress Estimation DOT share (%)	GDF Suez Estimated expenditure DOT share
1	1	1	3 months	$ 2 056	$ -	100	$ 2 056
2	2	1	6 months	$ 616	$ 16 149	100	$ 616
3	3	1	6 months	$ 6 676	$ 2 114	100	$ 6 676
4	4	1	18 months	$ -	$ -		$ -
5	5	1	24 months	$ -	$ 47 065		$ -
6	8	1	On-Going	$ 411	$ 242	100	$ 411
		1	**31/08/2008**	**$ 9 759**	**$ 65 569**	**$ 400**	**$ 9 759**
7	2	2	6 months	$ -	$ 16 149		
8	3	2	6 months	$ 2 003	$ 1 177	100	$ 2 003
9	4	2	18 months		$ -		$ -
10	5	2	24 months	$ 34 559	$ 37 426	100	$ 34 559
11	8	2	On-Going	$ 411	$ 242	100	$ 411
		2	**30/11/2008**	**$36 973**	**$54 994**		**$ 36 973**
12	4	3	18 months	$ -	$ -		
13	5	3	24 months	$ 33 270	$ 26 439	100	$ 33 270
14	6	3	12 months	$ -	$ -		$ -
15	8	3	On-Going	$ 411	$ 242		$ -
		3	**28/02/2009**	**$33 681**	**$26 681**		**$ 33 270**
16	4	4	18 months	$ -	$ -		
17	5	4	24 months	$ 35 819	$ 46 463	100	$ 35 819
18	6	4	12 months	$ -	$ -		$ -
19	8	4	On-Going	$ 411	$ 242	100	$ 411
		4	**31/05/2009**	**$36 230**	**$46 705**		**$ 36 230**
20	4	5	18 months	$ -	$ -		
21	5	5	24 months	$ 44 872	$ 35 068	70	$ 31 410
22	8	5	On-Going	$ 411	$ 242	100	$ 411
		5	**31/08/2009**	**$45 283**	**$35 310**		**$ 31 821**
23	4	6	18 months	$ -	$ -		
24	5	6	24 months	$ 1 500	$ 12 650		
25	6	6	18 months	$ 16 174	$ -		
26	8	6	On-Going		$ 242		
		6	**30/11/2009**	**$17 674**	**$12 892**		
27	5	7	24 months		$ 32 599		
28	8	7	On-Going		$ 242		
		7	**28/02/2010**	**$0**	**$32 841**		
29	5	8	24 months		$ 16 692		
30	7	8	24 months	$ 5 752	$ 1 372		
31	8	8	24 months				
32	8	8	24 months				
33	8	8	24 months	$ 3 339	$ 6 944		
		8	**31/05/2010**	**$9 091**	**$25 009**		
34	8		As Directed				
35	8		As Directed				
				$188 691	**$300 000**		**$148 053**