QUARTERLY REPORT
Project WP#339: Structural Significance of Mechanical Damage

For Period Ending: February 28, 2010

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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List of Activities and Deliverables

Task No.	Task	Scheduled Completion Date	Completed Date	Milestone
2	Purchase & Characterize Pipe Material	11/30/2008	Ongoing (Vintage Pipe 3)	
3	Literature Review	06/30/2009	Completed 11/30/2009	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 Mechanical 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 sixth 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
- Task 8 – Project Management and Reporting

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

There are three different pipe steels in this program:

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

- Pipe 3 is intended 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.

As indicated in prior progress reports, a potential source was identified that could manufacture Pipe 3 with properties replicating those observed for lower toughness pipes found in the 1950's or 1960's era pipelines. A manufactured source was identified as the preferred option in order to provide test pipe that was not affected by the variability introduced by unknown operations (i.e., such as pressure cycling over time and other operational factors/considerations). This would also limit material characterization costs, as a manufactured source would be from one manufacturing

batch and require only one characterization vs. multiple sources of vintage pipe. However, based on further discussions that occurred during this quarterly reporting period with the prospective manufacturer, the project technical team, and PHMSA, it is likely that the sources for the vintage pipe will be from former in-service pipelines provided through contributions by PRCI's member companies. Recent vintage pipe materials have become available and are believed to be consistent with the material properties needed for the project (this needs to be confirmed through material characterization and testing). The vintage pipes are available immediately and there is no manufacturing lead time, which will improve schedule controls and maintain momentum on the project. In addition, there are two primary sources of vintage pipe identified that are believed to be sufficient to meet the material needs for the program, which should help limit material characterization costs.

A contract modification request had previously been submitted to PHMSA in August 2009 regarding the vintage pipe manufacture and has been under review by PHMSA since that time. Based on the adjustment regarding the sources for vintage pipe, a revised version of the modification request was prepared and issued to PHMSA in February 2010. The revised modification includes the acquisition and characterization of vintage pipe using former in-service pipes. Preliminary material characterization test are being planned at this time and will be initiated upon approval of the revised contract modification request.

GDF SUEZ has received three samples of Pipe 1 and two samples of Pipe 2 all with a length of 11.8 m. Pipe 1 is API X52 grade and has a 24 in diameter and 7.9 mm wall thickness. Pipe 2 is API X70 grade. It also has a 24 in diameter but has a wall thickness of 9.0 mm. IPSCO manufactured the pipe using the electric resistance welding (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
- Size of slip bands (Additional originally unplanned work)

Task 3: Literature Review

The literature review regarding cyclic fatigue dent assessment techniques is complete. A report summarizing the findings and demonstrating the performance of the identified assessment techniques will be available following the completion of the testing.

Task 4: Testing of Dents on Welds and Corrosion Features

The testing of all dents interacting with girth welds has been completed. A general review and comparison of the results has been carried out to identify general trends. A summary of the findings is presented in later in the report.

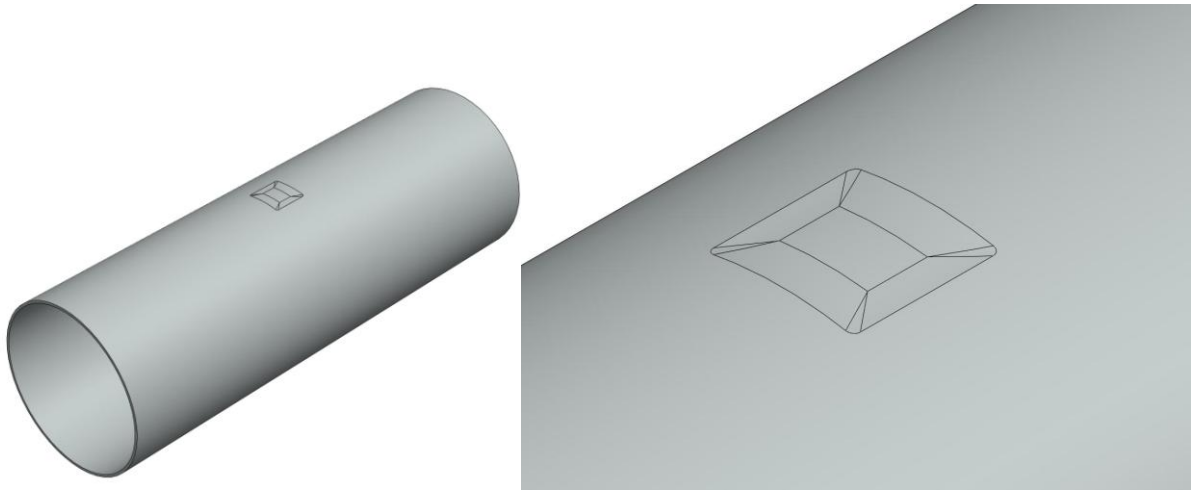


Figure 1: Simulated Corrosion Feature

The final test matrix for dents interacting with simulated corrosion features, shown in Table 1 below, has been approved by the project team at the PRCI Research Exchange meeting in Atlanta (February 11-13). Fabrication of the corrosion features and testing will begin in the coming quarter.

Table 1: Final Test Matrix – Dents Interacting with Simulated Corrosion Features

Test #	Specimen ID	Pipe Material	Nominal Indenter Diameter	Indenter Travel	Dent Depth	Dent Restraint	Interacting With	Indentation Pressure	Second Pressure Cycle	Cyclic Pressure Range	Indenter Location
			(in)	(%)	(%)				(%SMYS)	(%SMYS)	
35	26	A	4	10	10	R	Metal Loss	30	80%	10%-80%	C.L
36	30	A	4	10	10	R	Metal Loss	0	80%	10%-80%	C.L
37	37	A	4	15	~3-5	U	Metal Loss	30	80%	10%-80%	C.L
38	38	A	4	15	~3-5	U	Metal Loss	0	80%	10%-80%	C.L
39	39	B	4	5	5	R	Metal Loss	0	80%	10%-80%	1" Offset
40	40	B	4	15	~3-5	U	Metal Loss	0	80%	10%-80%	1" Offset

Task 5: Testing of Dents with Gouges

GDF SUEZ is in charge of the creation, characterization, burst test, and fatigue test of realistic combined defects, i.e., "dents with gouges", and their program is 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; two extreme aggression conditions are considered in this study: highly dynamic and slower aggression. The former corresponds to defect Types 1 and 2 for Pipe 1 (two different excavator teeth used) and Type 1 for Pipe 2, while the latter corresponds to Type 3 for Pipe 1 and Type 2 for Pipe 2.

- 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 13 defects (11 + 2 repeated ones): 1.1.1, 1.1.1b, 1.1.2, 1.1.3, 1.2.1, 1.2.1b, 1.2.2, 1.3.1, 1.2.3, 2.1.1, 2.1.2, 2.1.3 and 2.2.1
- 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 and one in Pipe 2 : 2.1.3
- Metallurgical Failure Investigation for 3 defects: 1.1.2, 1.1.3, 1.2.2 and 2.1.3

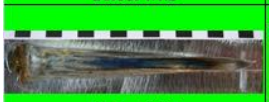
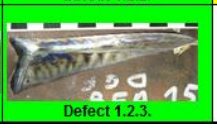
This report presents:

- The cyclic hardening behavior of Pipe 1 and Pipe 2
- Defect creation and characterization of defect 1.3.2 and 2.2.2.

Table 2 below summarizes the progress of the task on "Dent and Gouge" defects for the entire program. The background color in the table represents:

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

Table 2: Status of "Dent and Gouge" defects for the entire program

MD 4-1				
Pipe 1 (current steel X52)			Pipe 2 (current steel X70)	
Type 1	Type 2	Type 3	Type 1 or 2	Type 2 or 3
Defect 1.1.1b	Defect 1.2.1b	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*

Business Status

The project remains well coordinated with the pipeline industry through the PRCI partnership on the project.

Funds Expended

The financial condition of the project is shown in Table 3 below. Please note that a contract modification was submitted to DOT which will affect the budget.

Table 3: Status of the budget for the Project

		Federal Funding			Cost Share Funding			
Item # per MS	**Task # Task Description**	**Budget**	**Expended (Actuals) This Quarter**	**Expended (Actuals) to Date**	**Budget**	**Expended (Actuals) This Quarter**	**Expended (Actuals) to Date**	**% Task Work Completed**
1	Project Kick Off Meeting and Subcontracting	$9,335	$0	$9,335	$831	$0	$831	100%
2	Purchase & Characterize Pipe Material	$34,674	$0	$19,567	$96,108	$16,149	$96,108	65%
3	Literature Review	$11,549	$0	$11,549	$8,669	$2,114	$8,668	100%
4	Testing of Dents on Welds & Corrosion Features	$188,507	$0	$157,363	$599,631	$0	$561,250	65%
5	Testing of Dents with Gouges	$150,020	$0	$150,020	$254,403	$0	$205,111	75%
6	Demonstration of Mechanical Damage Model Performance	$22,008	$0	$0	$10,930	$0	$10,930	0%
7	Industry Workshop	$12,030	$0	$0	$4,325	$0	$1,372	0%
8	Project Management and Reporting	$73,694	$7,336	$53,408	$43,959	$4,242	$40,879	On-going
	GRAND TOTAL	**$501,818**	**$8,836**	**$393,906**	**$1,018,856**	**$22,505**	**$790,373**	

Schedule

The project is generally on schedule, but as discussed in prior reports, Task 5 is impacted by the shutdown of the neutron diffraction facility at Chalk River. This delay impedes the detailed characterization of defects of Index 1. Note, the analysis of the defect samples using neutron diffraction was not included in the original scope of work and was added to the program on a voluntary, no-cost basis.

Finally, the team has provided revised documents to DOT and expects to receive approval for a contract modification in the next quarterly period to support the procurement of manufactured vintage pipe for the DOT sponsored tests and to provide for a schedule extension from 24 to 48 months.

Payable Milestones

Task status for this period is shown in Table 4. Please note a modification was submitted to DOT to extend the schedule.

Table 4: Status of Tasks for Project

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	65% 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	
5	Testing of Dents with Gouges	75 % Complete	5/31/2010	
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	28

Results and Conclusions

A summary of the results are:

- Task 2—Cyclic hardening tests were done in transverse direction for Pipe 1 and Pipe 2. The results show a Bauschinger effect with softening behavior for both materials.
- Task 3—The literature review regarding cyclic fatigue dent assessment techniques is complete.
- Task 4— The testing of dents interacting with girth welds has been completed.
- Task 5—The team created dents with gouges on defects 1.3.2 and 2.2.2 with a slower aggression and then characterized defects 1.3.2 and 2.2.2, similar to defects 1.3.1 and 2.2.1. It reached with a maximum 5.7% dent depth and gouge depth of 29% for defect 1.3.2 and a maximum 5% dent depth and gouge depth of 16.7% for defect 2.2.2. Such a deep dent required an internal pressure during defect creation of 30 bars for Pipe 1 (defect 1.3.2) and 20 bars for Pipe 2 (defect 2.2.2)

Task 2: Material Characterization – Cyclic hardening tests on materials pipe 1 and pipe 2

Cyclic hardening tests were done for Pipe 1 and Pipe 2 for different ranges of strain amplitudes: [-0.2%, +0.2%], [-0.5%, +0.5%], [-1.0%, +1.0%], [-1.5%, +1.5%],

The team at GDF SUEZ observed a Bauschinger effect with softening behavior for both materials. Figure 2 shows cyclic curves data for Pipe 1.

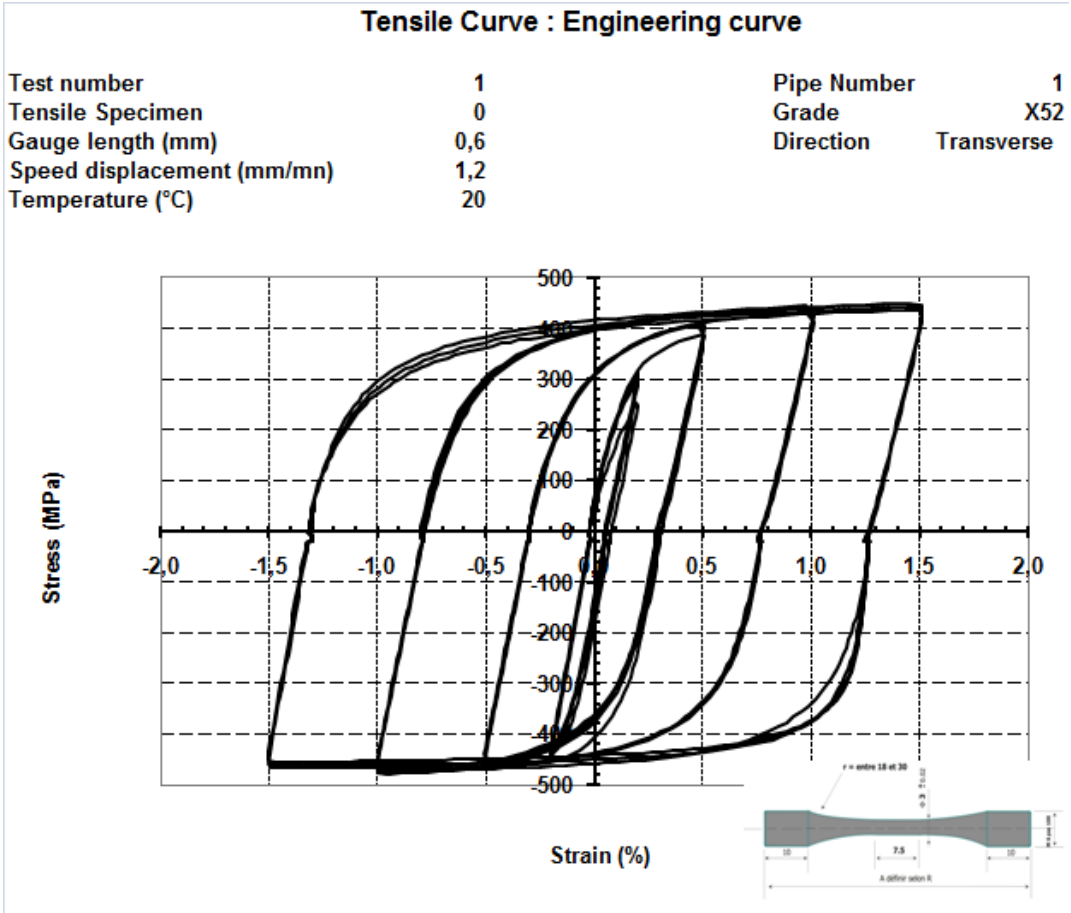


Figure 2: Kinematic hardening behavior for Pipe 1

Task 4: Testing of Dents on Welds and Corrosion Features

The testing of dents interacting with girth welds has been completed. A review of the results to date is presented in the figures below.

Figure 3 presents a summary of the experimental fatigue lives for each of the specimens, where the blue bars represent restrained dent specimens and red bars represent unrestrained specimens.

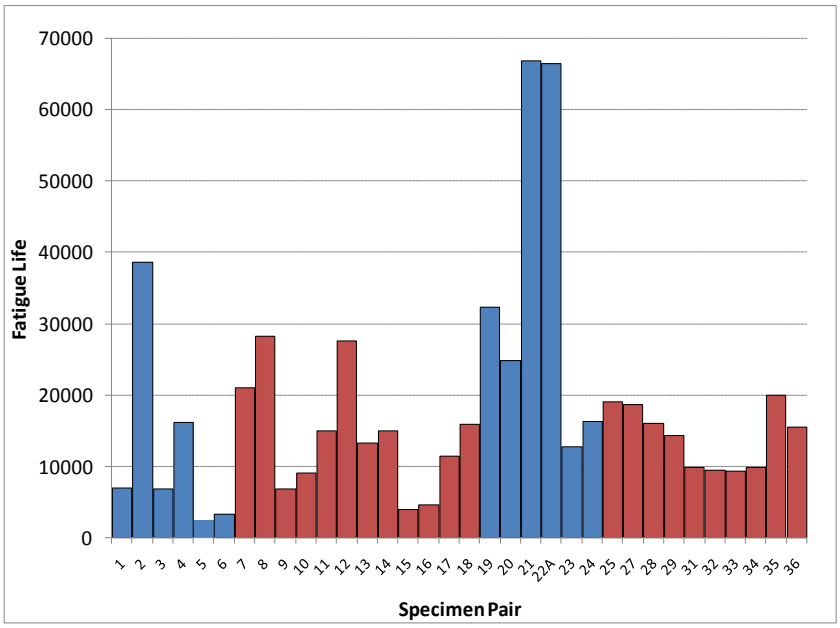


Figure 3: Experimental Fatigue Lives – Plain Dents and Dents Interacting with Welds

Figure 4 presents the final rebounded dent depth prior to cyclic fatigue loading. As shown, the dent depths for the restrained dents are deeper than the rebounded dent depths exhibited by the unrestrained dent specimens.

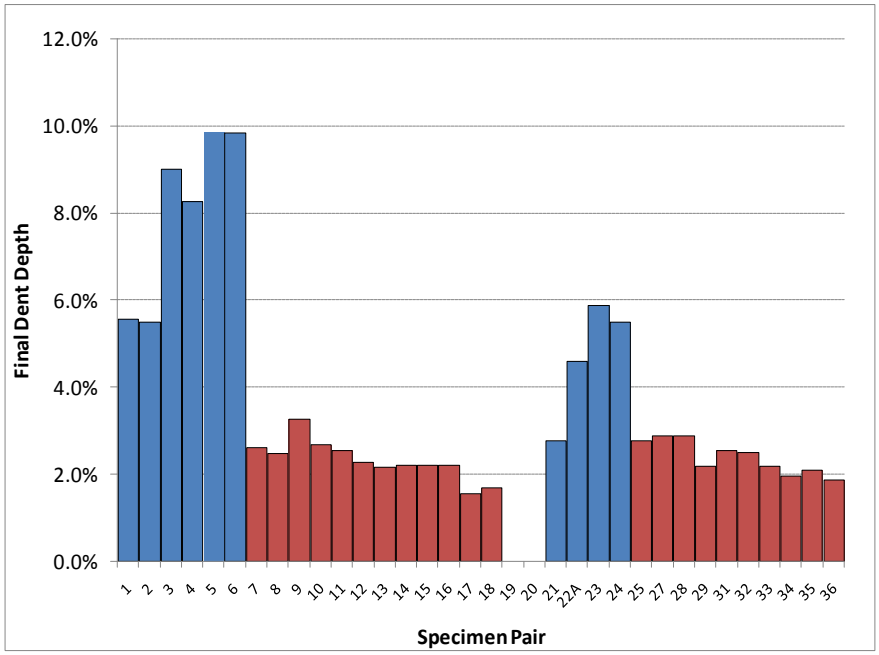


Figure 4: Final Rebounded Dent Depth Prior to Fatigue Cycling

Figure 5 presents and compares the experimental fatigue life curves for plain unrestrained dents in Pipe A and Pipe B. The curves relate the experimental fatigue life to the dent depth prior to fatigue cycling. The curves represent the combined effect the different material grades and the wall thicknesses have on both the dent depth and the experimental fatigue lives.

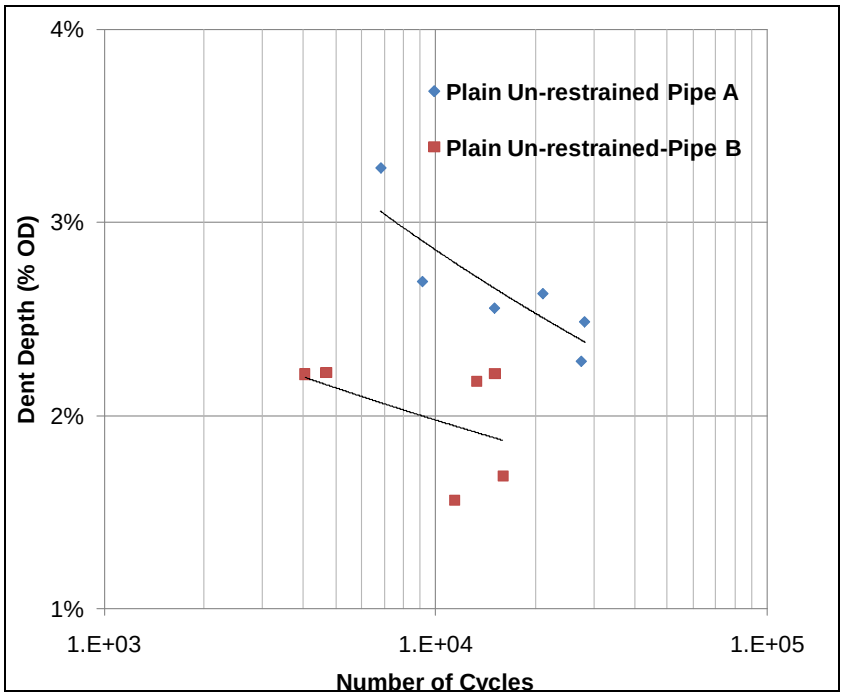


Figure 5: Experimental fatigue life curves for plain unrestrained dents in Pipe A and Pipe B

Figure 6 shows similar experimental fatigue life curves for both plain restrained dents and restrained dents interacting with girth welds.

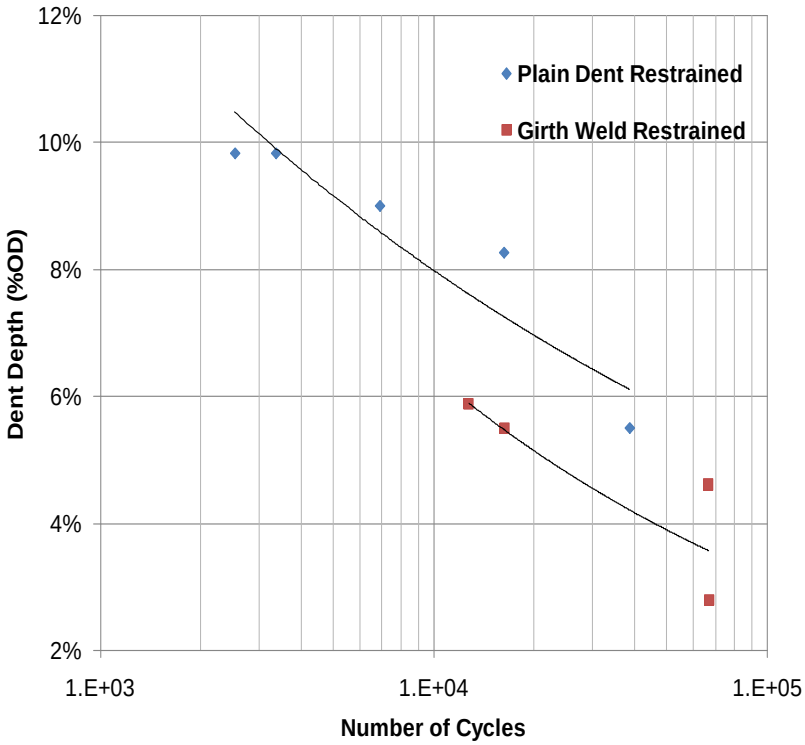


Figure 6: Experimental fatigue life curves for both plain restrained dents and restrained dents

Task 5: Testing dents with gouges: Creation and characterization of defects 1.3.2 and 2.2.2.

The team created defects 1.3.2 and 2.2.2 similar to defects 1.3.1 and 2.2.1 with a slower aggression procedure. The defects were created under internal pressures respectively of 30 and 20 bar in order to ensure producing a deep dent. Force versus displacement curves are plotted below in Figure 7 and Figure 8

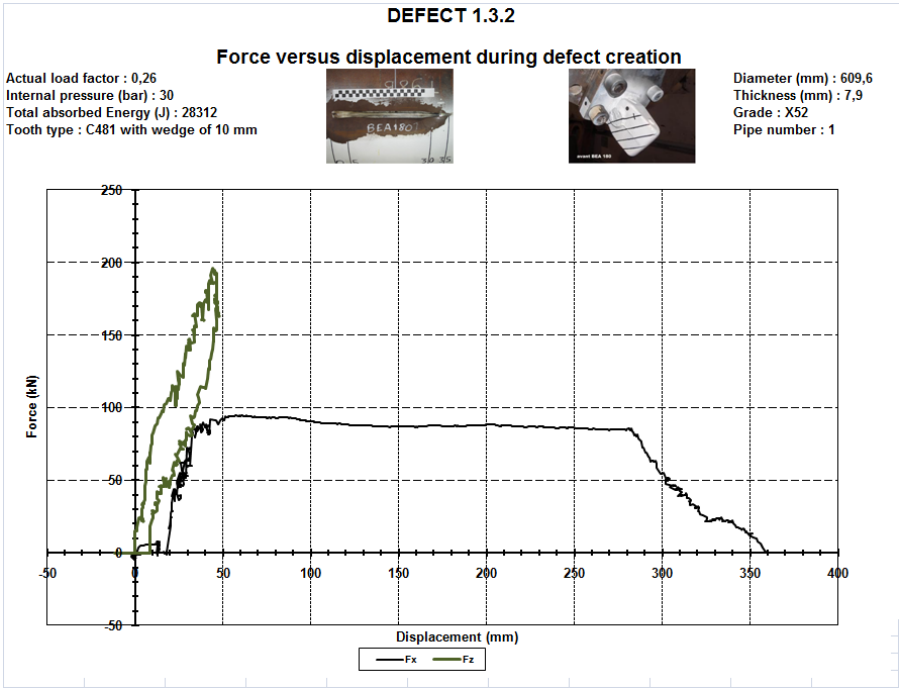


Figure 7: Force-displacement curve for creation of defect 1.3.2

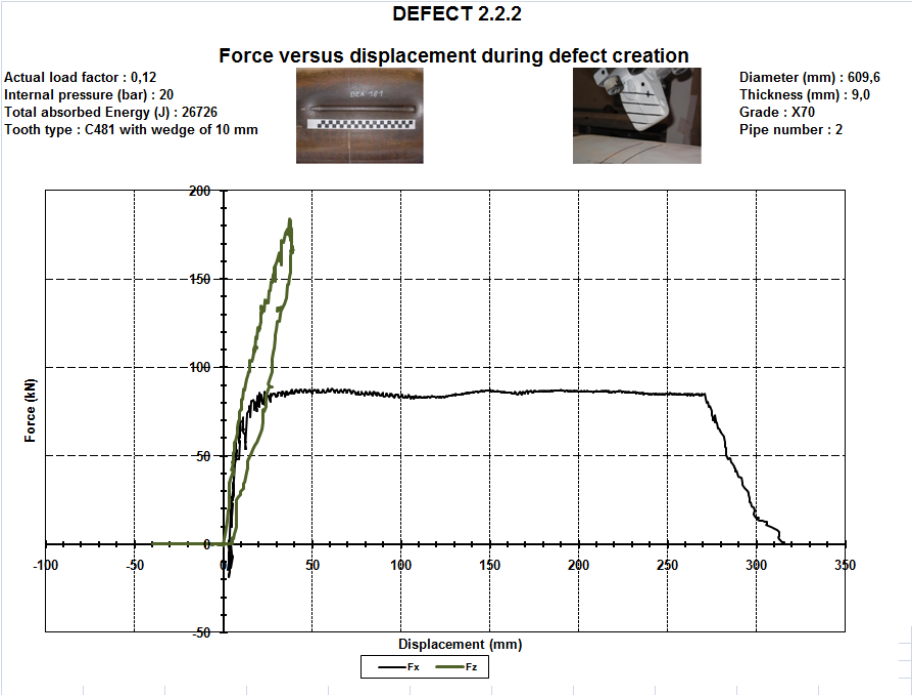


Figure 8: Force-displacement curve for creation of defect 2.2.2

Magnetic particle inspection (MPI) did not reveal the presence of cracks or micro-cracks at the bottom of the gouge for either defect (Figure 9).

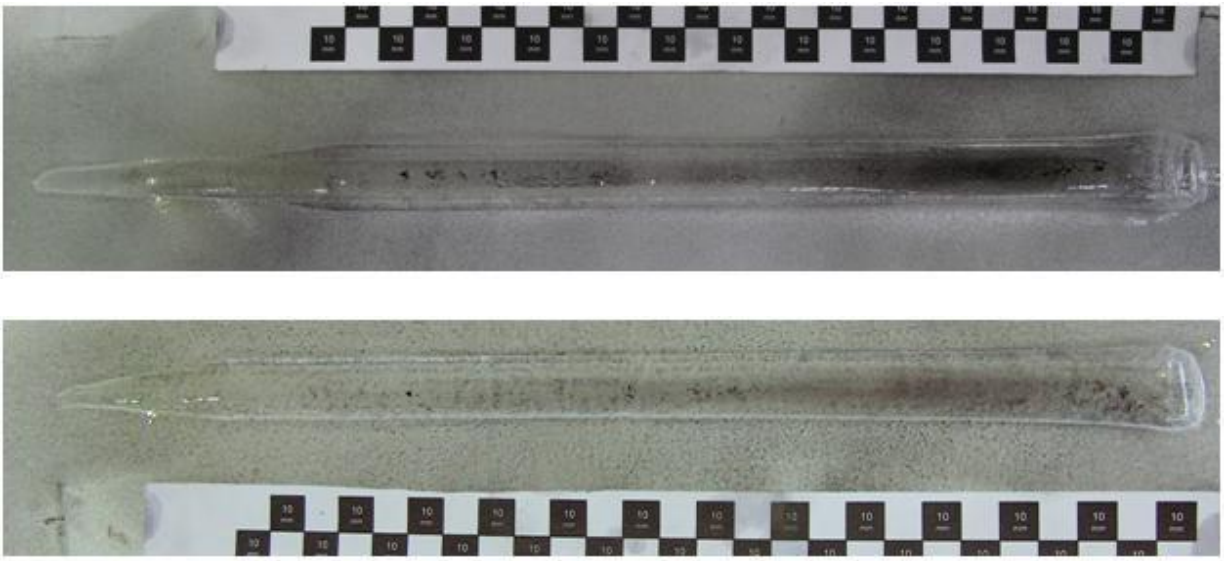
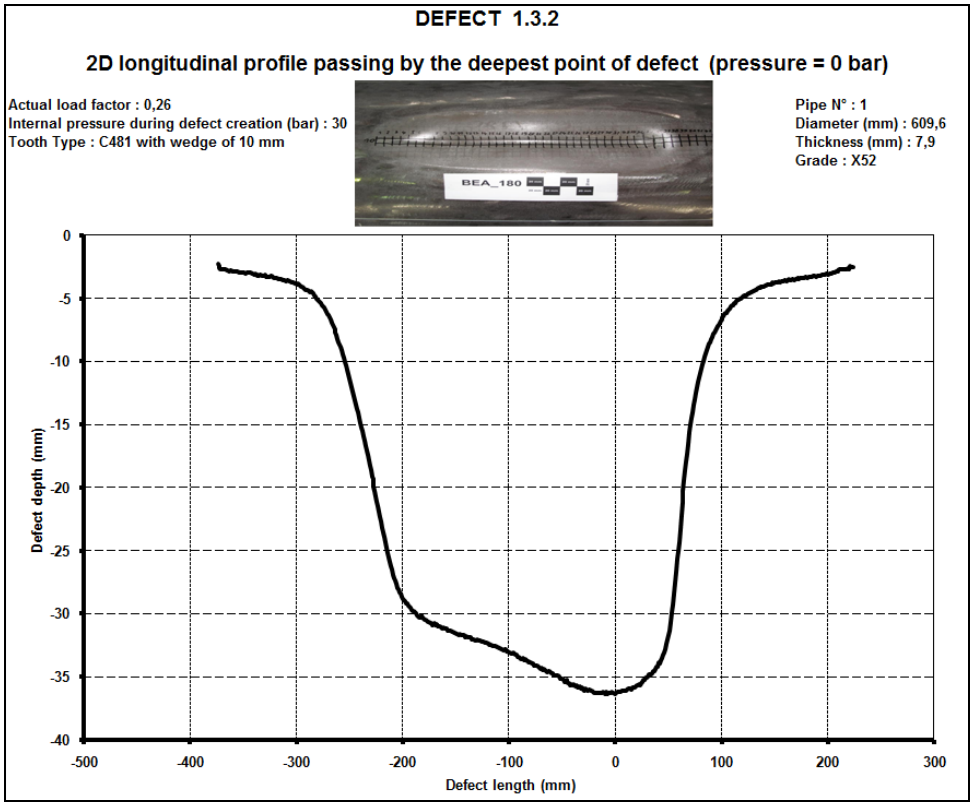


Figure 9: Defect 1.3.2 (above) and 2.2.2 (below). - No crack or micro-crack was indicated by magnetic particle inspection

The appearance of these defects is illustrated in Figure 10 below.

Figure 10: Side view of defect 1.3.2.

For each defect two-dimensional profiles in longitudinal and transverse pipe directions passing by the deepest point of defect 1.3.2 and 2.2.2 are respectively presented in Figure 11 and Figure 12.



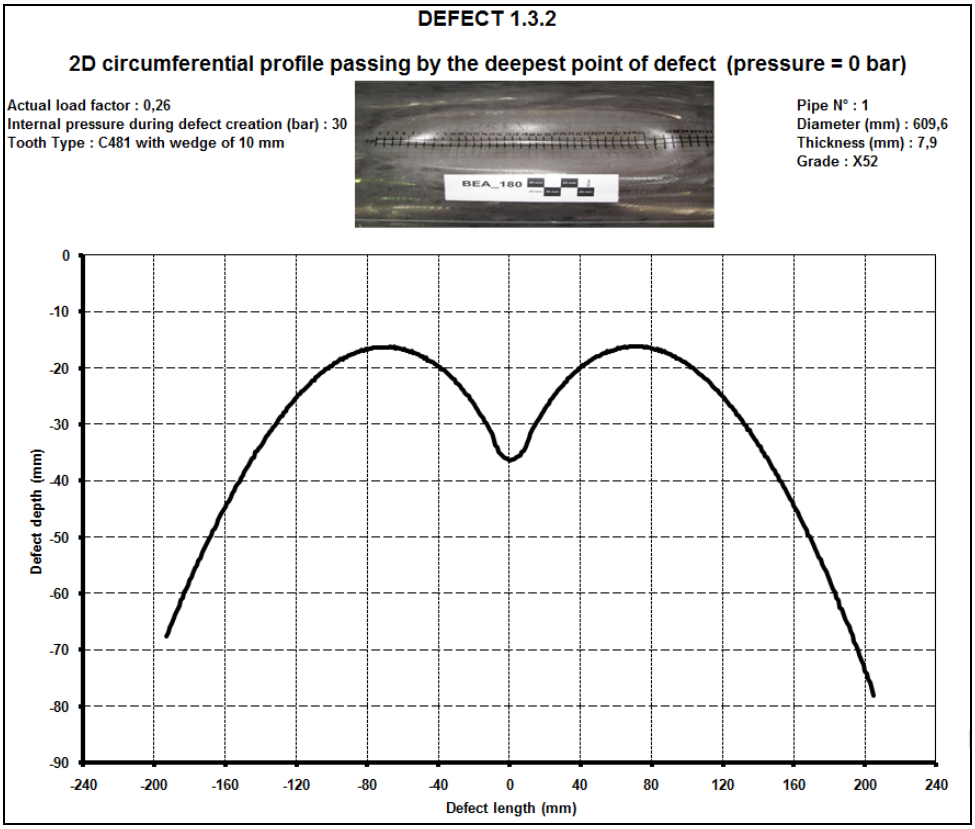
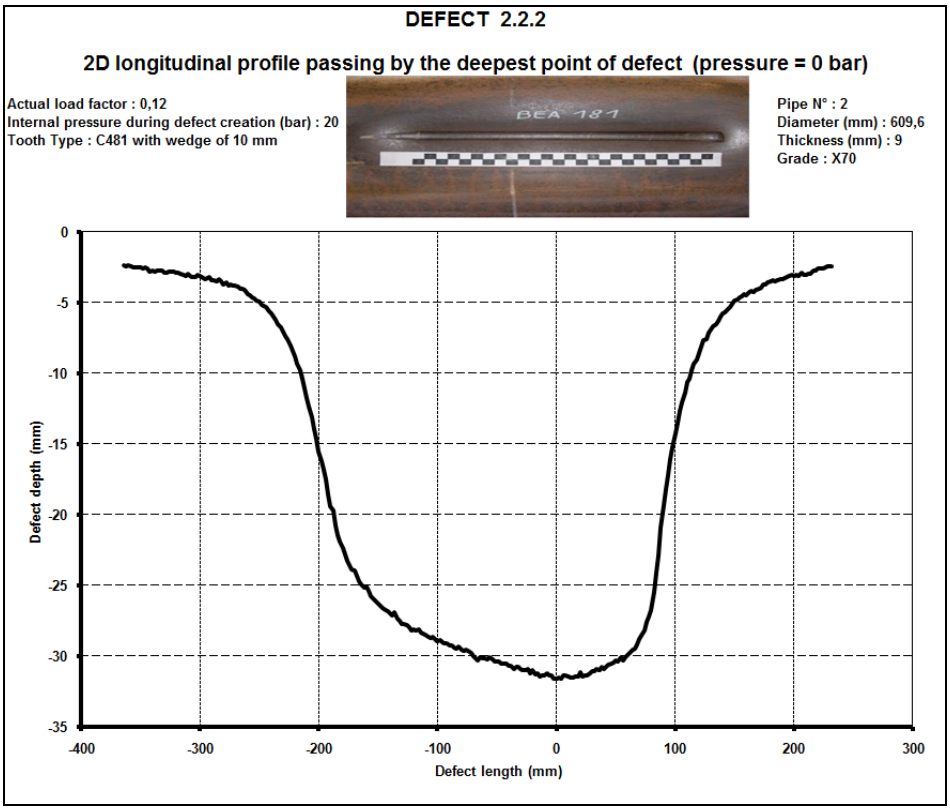


Figure 11: Defect 1.3.2 – 2D Longitudinal and Transverse Profiles at no pressure



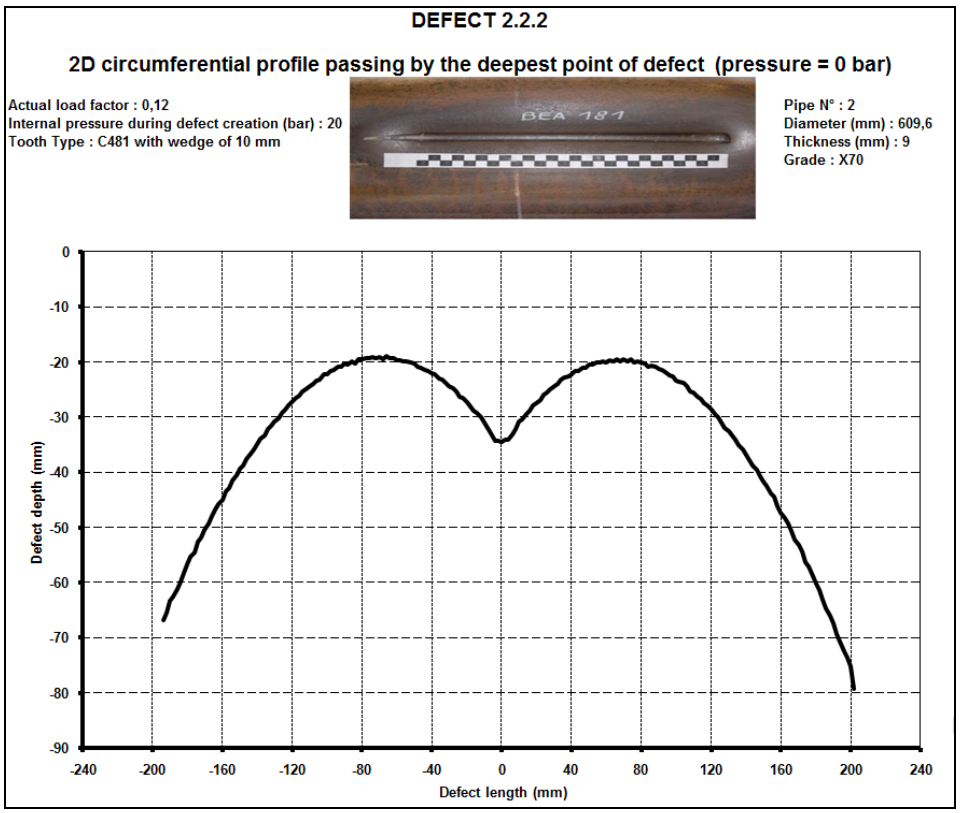


Figure 12: Defect 2.2.2 – 2D Longitudinal and Transverse Profiles at no pressure

Task 8: Project Management and Reporting

A revised version of a previous August 2009 contract modification request was submitted to PHMSA to address a change in the approach for acquiring and testing of vintage pipe materials needed for the testing program (Pipe 3). The updated modification request included a revised milestone schedule, extending the project schedule from the original 24 month period to 48 months. The additional time is related to the extension required to complete the testing program on the vintage pipe materials, as there was delay in identifying and confirming sources for the vintage pipe.

The Project Technical Team participated in a program review meeting at the PRCI 2010 Research Exchange Meeting in Atlanta, GA, held on February 10, 2010. The review meeting was broadly attended, with more than 50 participants from the pipeline industry present. The meeting included not only the specific technical elements of the PHMSA-sponsored project on the structural significance of mechanical damage, but a number of other PRCI research projects that are directly linked to the database being developed under this project, including the development of models to assess the effects of dents and dent+gouge features on pipeline integrity.

Issues, Problems or Challenges

- GDF SUEZ measures the residual stresses in defects called x.x.1 on the same vessel for a given material. This process avoids wasting material by using the same vessel for different x.y.1 defects. However, 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).

- The team is planning on delaying the demonstration of mechanical models until 2010 to include the results from the vintage pipe testing program and, therefore, provide for a more substantial set of data for the analysis.

- The process to mark the cracks and micro-cracks by ink injection in “dent and gouge” defects was not satisfactory. The team is developing a new or modified process.

- A number of adjustments and modifications have been made to the program to improve the outcomes and generate additional and/or more robust data. These changes have included additional tests (e.g., neutron diffraction), additional instrumentation to expand/improve the data collected during the tests, and related coordination, planning, and management to implement the modifications. The project team is attempting to offset any cost increases associated with these changes by improvements in productivity. However, it may be necessary to request a contract modification to account for the costs directly attributed to these changes. This modification is expected to be prepared and submitted in the next quarterly period.

Plans for Future Activity

Planned activities for the project are presented below.

Task 2: Purchase & Characterize Pipe Material

Testing on vintage pipe material will begin once the materials are delivered to the test facilities (GDF SUEZ in Saint Denis, France, and Stress Engineering Services in Houston, TX, USA).

Task 4: Testing of Dents on Welds and Corrosion Features

Testing of the dents on simulated corrosion features will begin in the coming quarter. It is anticipated that the testing will also be concluded in the coming quarter.

Task 5: Testing of Dents with Gouges

GDF SUEZ will perform burst tests of defects 1.3.2 and 2.2.2 and will launch the creation of defects 1.3.3 and 2.2.3. They will also perform X-ray diffraction to determination of residual stresses on internal and external surfaces of defects 1.3.1 and 2.2.1.