ATI SAA Annex III Button Tensile Test Report I

Crew and Thermal Systems Division

November 30, 2013
Revision: Basic

Crew and Thermal Systems Division
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November 30, 2013

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Change Record

Rev	Date	Originator	Description
Basic	November 30, 2013	Henry H. Tang	Initial Release

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Tables and Figures

1.0 Background

This report documents the results of a study carried out under Space Act Agreement SAA-EA-10-004 between the National Aeronautics and Space Administration (NASA) and Astro Technology Incorporated (ATI). NASA and ATI have entered into this agreement to collaborate on the development of technologies that can benefit both the US government space programs and the oil and gas industry.

The report documents the results of a test done on an adhesive system for attaching new monitoring sensor devices to pipelines under Annex III of SAA-EA-10-004: "Proof-of-Concept Design and Testing of a Post Installed Sensing Device on Subsea Risers and Pipelines". The tasks of Annex III are to design and test a proof-of-concept sensing device for in-situ installation on pipelines, risers, or other structures deployed in deep water. The function of the sensor device is to measure various signals such as strain, stress and temperature. This study complements the work done, in Annex I of the SAA, on attaching a fiber optic sensing device to pipe via adhesive bonding. Both Annex I and Annex III studies were conducted in the Crew and Thermal System Division (CTSD) at the Johnson Space Center (JSC) in collaboration with ATI.

2.0 Introduction and Objective

A series of "button tensile tests" was conducted to measure the bonding strength of several prototype adhesive sensor clamps attached to three 24" diameter steel pipes. The prototype adhesive sensor clamp was jointly developed by ATI and NASA JSC, and it is referred to as "clamp" in the rest of this document. The clamp body was made with polyurethane (PU) and was attached to a steel pipe using Syntho-Subsea LV epoxy adhesive. The clamps were attached to the test pipes in a clamp installation test conducted by ATI to practice the installation of the adhesive sensor clamps underwater. The "button tensile test" is a z-direction tensile test for measuring in-plane adhesive strength using a cylindrical shape "button" specimen. The "button tensile test" is a non-standard yet practical method to perform tests on large structures. A three dimensional (3-D) model of the "button tensile test" setup is shown in Figure 1, Button Tensile Test Setup 3-D Model.

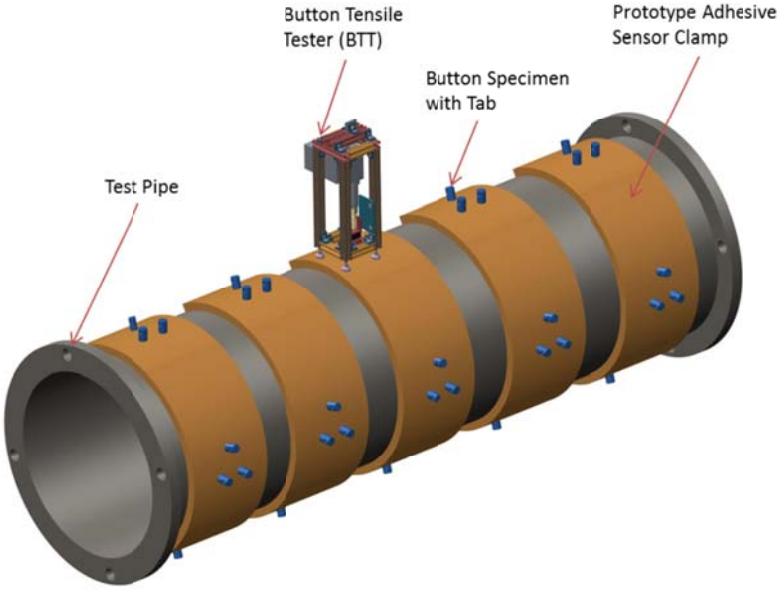

Figure 1. Button Tensile Test Setup 3-D Model

There are two objectives for performing the button tensile tests. The primary objective is to determine the strength of the bond formed by the subsea adhesive used in attaching the clamps to the pipes. The secondary objective is to evaluate the bonding characteristics of the adhesive used in the clamping system. Nine clamps and three pipes were used in this study. Seven clamps were installed underwater by a diver during the ATI clamp installation test, and 2 clamps were installed at the ATI facility. At the end of the study nearly 240 button tensile tests had been performed. All the tests were conducted at the ATI facility between May 28, 2013 and September 17, 2013. NASA JSC provided test equipment and personnel for these tests. Activities carried out by JSC and ATI are listed below:

1. Design the button tensile test protocol. (Joint JSC and ATI effort)
2. Develop test plan and procedures. (JSC effort)
3. Design and fabricate portable button tensile testing apparatus and data acquisition system. (JSC effort)
4. Manufacture and install 2 control clamps onto a 24” test pipe. (ATI effort)
5. Prepare button test specimens at ATI facility. (ATI effort)
6. Perform button tensile testing at ATI facility. (JSC effort)
7. Analyze data and document test results. (JSC effort)

3.0 Reference Documents

The following are documents related to this study.

- SAA-EA-10-004-3, Annex No. 3 between the Astro Technology Incorporated and NASA for Proof-of-Concept Design and Testing of a Post Installed Sensing Device on Subsea Risers and Pipelines
- STB-JHA-214, Job Hazard Analysis - Operation of the Portable Button Tensile Tester
- TPS 101320014, Calibrate Load Cell for Adhesive Test

Note: All References must be reviewed prior to use to verify that the document is the latest version.

4.0 Symbols and Abbreviations

3-D	Three Dimensional
AML	Advanced Materials Laboratory
ATI	Astro Technology Incorporated
ATS	Adhesive Tensile Strength
BTT	Button Tensile Tester
CTSD	Crew and Thermal Systems Division
DAQ	Data Acquisition System

FTRA	Force Time Response Analysis
EA	Engineering Directorate
Hz	Hertz (data points per second)
ID	Identification
in	Inch
JHA	Job Hazard Analysis
JSC	Johnson Space Center
lbf	Pound-Force
min	Minute
MSDS	Material Safety Data Sheet
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
No	Number
PSI	Pounds per Square Inch
PU	Polyurethane
SAA	Space Act Agreement
S.D.	Standard Deviation
SOW	Statement of Work
STB	System Test Branch
TBD	To Be Determined
TPS	Task Performance Sheet

5.0 Test Methodology

The primary objective of the button tensile test is to determine the force required to break the adhesive bond between a clamp and a test pipe. Due to the size and weight of the 24" diameter steel pipes, it would have been difficult to transport and adapt the pipes to the standard universal testing machine available at JSC. Therefore, a portable button tensile tester (BTT) was designed and built to perform the testing at the ATI facility.

Button specimens were made by carefully cutting several cylinders through each clamp-adhesive-pipe assembly without breaking or weakening the adhesive bond between the clamp and pipe surface. A test tab was bonded on top of each button specimen to act as the attachment and loading interface for the BTT. Once attached to the tab, the BTT applied an axial tensile force normal to the bonding surface to break the adhesive bond and separate the polyurethane button from the steel pipe. A photograph of the button tensile test setup is shown in Figure 2, Button Tensile Test Configuration. The detailed descriptions of the test specimen, test equipment, and test procedure are included in the following sections.

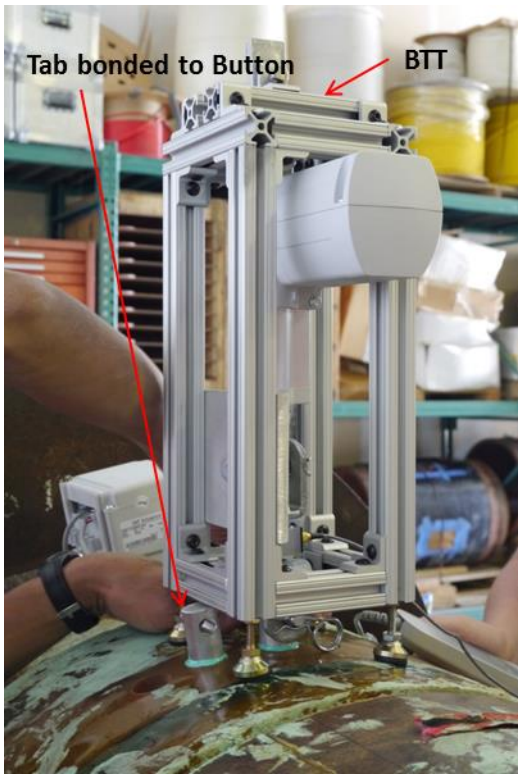

Figure 2. Button Tensile Test Configuration

5.1 Test Articles and Specimens Identification

The test articles for this study are three 24" diameter steel pipes and nine polyurethane clamps. These test pipes have dimensions similar to those of typical offshore platform tension legs. The main test article is a 13' long 24" diameter steel pipe with seven clamps. The other two test articles are 5' long 24" diameter steel pipes with one clamp attached to the surface of each pipe.

All the clamps were manufactured by ATI. Each clamp was approximately 1" thick and 12" wide with enough length to cover more than three-quarters of the pipe circumference. The clamps were casted with a Poly 81-Series polyurethane supplied by Polytek Development Corp. Only two of the nine clamps, clamps E and G, had sensors and wiring embedded in the polyurethane. A photograph of clamp E and G is showed in Figure 3, Clamps E and G with Embedded Sensors and Wiring. The sub-sea adhesive used to install all the clamps is Syntho-Subsea LV epoxy made by Neptune Research, Inc. The technical datasheets for Poly 81 Series polyurethane and for the Syntho-Subsea LV epoxy are included in Appendix A.

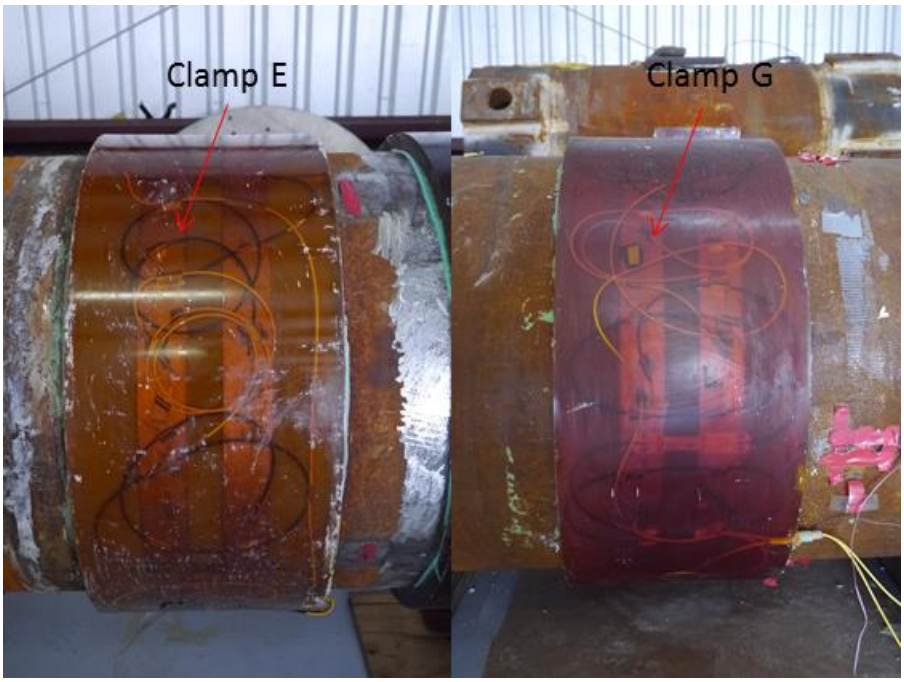

Figure 3. Clamps E and G with Embedded Sensors and Wiring

Five of the clamps on the 13' pipe and the 2 clamps on the 5' pipes were installed underwater by a diver. The installation of theses clamps was completed during a clamp installation test conducted by ATI. In the clamp installation test, a diver applied the adhesive and fastened the clamps onto the steel pipes submerged in a cylindrical water tank. After the installation, the adhesive was allowed to cure and set underwater for at least 24 hours. After curing, the 13' pipe along with the clamps was load-tested at various levels of bending, tension, and compression stresses. These load-tests verified the integrity of clamp bonding and verified that the sensors provided accurate stress measurements. After the load-testing, the pipes were stored in the ATI workshop in an uncontrolled ambient environment for more than six months before the button tensile testing started.

Two additional clamps were installed by ATI personnel onto the 13' pipe in the ATI workshop facility as control samples before the start of the button tensile testing. One of the control clamps was installed dry at ambient conditions and the other one was installed underwater at ambient conditions. Neither control clamp was load-tested after the installation. The two control clamps were allowed to cure for at least one week before being tested. Photographs of the 13' pipe with all the installed clamps labeled is shown in Figure 4, Pipe P1 with Clamp Labeling. The clamp labeling for the 5' pipes are shown in Figure 5, Pipe P2 with Clamp Labeling, and Figure 6, Pipe P3 with Clamp Labeling, respectively.

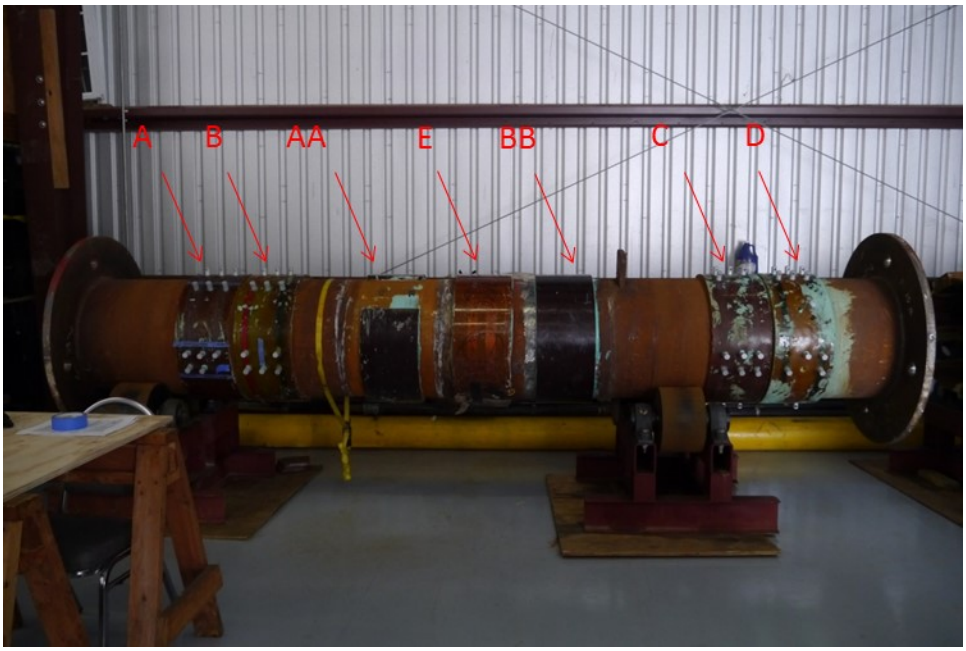

Figure 4. Pipe P1 with Clamp Labeling

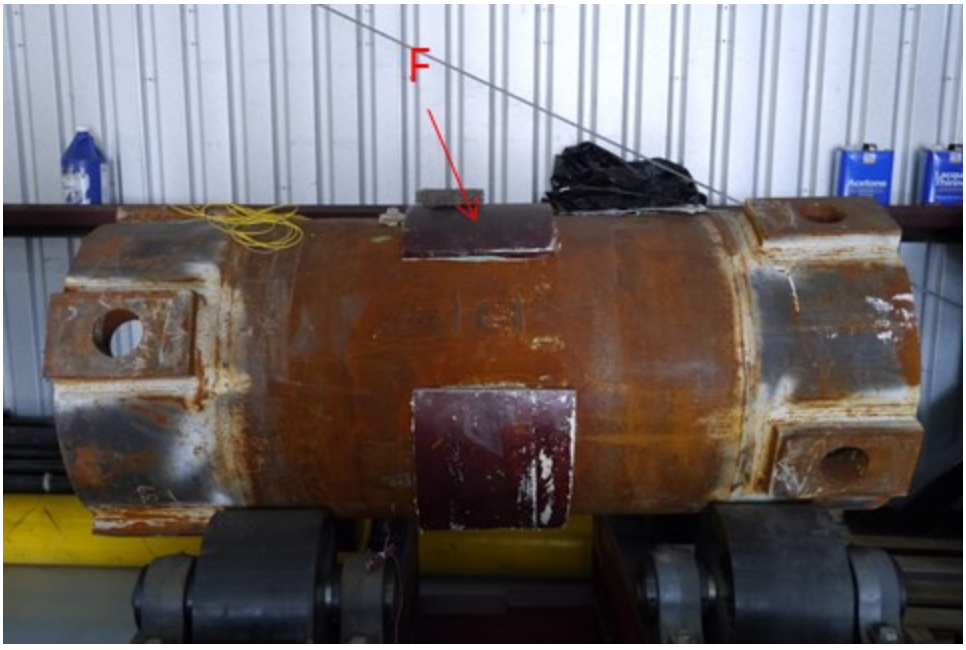

Figure 5. Pipe P2 with Clamp Labeling

Figure 6. Pipe P3 with Clamp Labeling

A labeling system was employed to identify each pipe, clamp, and button specimen in an organized format. The 13' pipe was labeled P1 and the two 5' pipes were labeled P2 and P3. The 9 test clamps were labeled by the initial letters of the alphabet. The 5 diver-installed clamps on pipe P1 were labeled A to E. The control clamp installed wet was labeled AA and the control clamp installed dry was labeled BB. The two clamps on pipes P2 and P3 were labeled F and G, respectively. Each pipe and clamp was divided into four quadrants and labeled N, S, E, and W. Test specimens were removed from each quadrant and labeled with their own numeric specimen numbers, e.g., 1, 2, 3, etc. Figure 7, Test Article and Specimen Labeling Schematic, graphically illustrates the labeling system. The full specimen identification (ID) number consists of all four ID numbers as described above, and the corresponding format is shown below:

Specimen ID Number = "Pipe ID" – "Clamp ID" "Quadrant" – "Specimen No." (e.g., P1-AN-1)

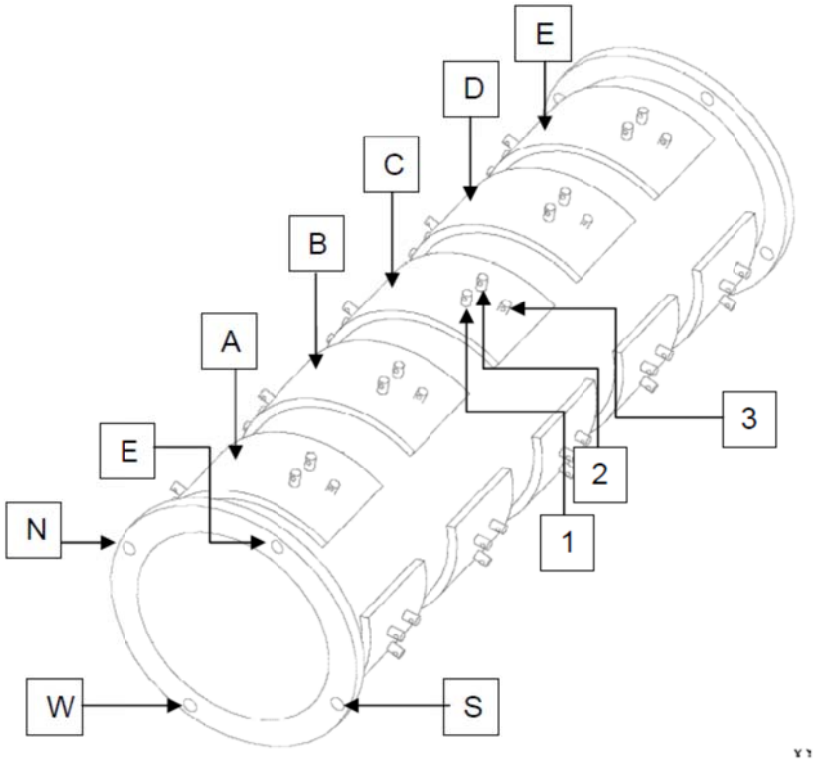

Figure 7. Test Article and Specimen Labeling Schematic

5.2 Test Equipment

A portable button tensile tester (BTT) was built by NASA JSC CTSD to conduct the testing at the ATI facility. A drawing of the BTT is shown in Figure 8, Drawing of the Portable Button Tensile Tester. The BTT consisted of an aluminum frame, an integrated linear actuator rated at a 1,000 lbf capacity and a hand switch controller with push/pull functions. A 1,000 lbf load cell was attached to the free end of the linear actuator. A pin connector fixture for interfacing with test specimen was connected to the load cell to provide direct force measurement. The measurement signals from the load cell were collected by a laptop computer with a data acquisition system (DAQ) created using LabVIEW software and hardware from National Instruments, Inc. The software and system were capable of acquiring time and load measurement data at a data acquisition rate of up to 500 Hz. A photograph of the BTT and the data acquisition system is shown in Figure 9, BTT and Data Acquisition System.

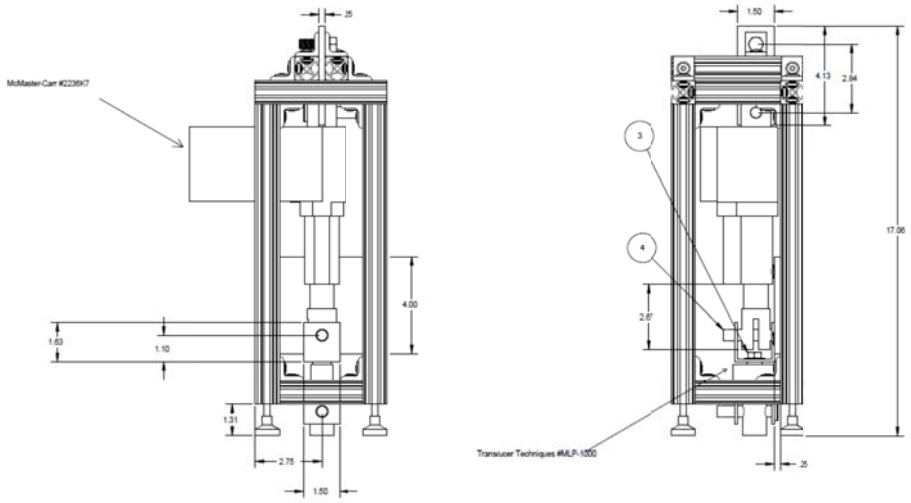

Figure 8. Drawing of the Portable Button Tensile Tester

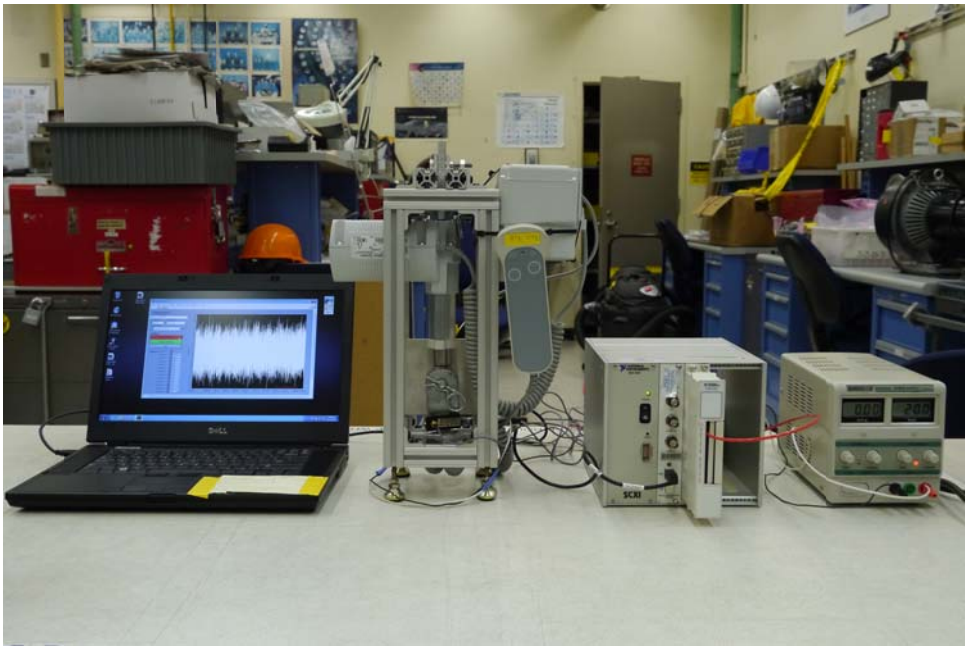

Figure 9. BTT and Data Acquisition System

5.2.1 Test Equipment Calibration

Calibration and functional testing were performed prior to the BTT and the DAQ being used for actual testing. The load cell of the BTT and the DAQ were calibrated to ensure accurate measurement. The calibration was performed using JSC Task Performance Sheet (TPS) number 101320014, Calibrate Load Cell for Adhesive Test. The functional test was conducted to verify the functionality of the test system and the test setup.

5.2.2 Test Equipment Functional Test

After the completion of the calibration test, the test system was subjected to a series of functional tests. The primary objective of the functional tests is to verify the functionality and operation of the BTT and the test method. The secondary object is to provide an opportunity for the test operators to practice their techniques in working with test specimens and operating the BTT in a controlled environment.

The functional tests were conducted in the CTSD Advanced Materials Laboratory (AML). The functional tests involved testing the button specimens prepared using the same Syntho-Subsea LV adhesive and bonding substrates as in the ATI pipe/clamp test articles. The tests were conducted with the calibrated BTT and DAQ. The bonding strength between the tab and polyurethane were measured to assess if the system was functioning properly.

A schematic of the functional test specimen setup is shown in Figure 10, Button Tensile Tester Functional Test Specimen and Test Setup. The test setup consisted of a base plate that mounted directly to an immovable surface, a 3" x 3" sample plate bolted to the base plate, a 1.5" x 1.5" polyurethane sheet bonded to the sample plate, and a 1" diameter tab bonded to the polyurethane sheet. The tab was approximately 2" long and has a transverse through-hole that allows it to be pinned directly to the connecting fixture of the BTT. The adhesive was allowed to cure for at least 24 hours prior to being tested. This test setup was designed to measure the adhesive bonding strength between the tab and the polyurethane sheet. A photograph of the functional test setup with the BTT is shown is Figure 11, System Functional Test Setup.

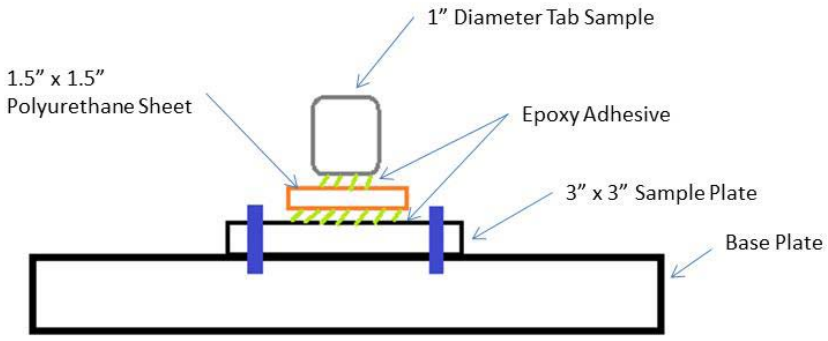

Figure 10. Button Tensile Tester Functional Test Specimen and Test Setup

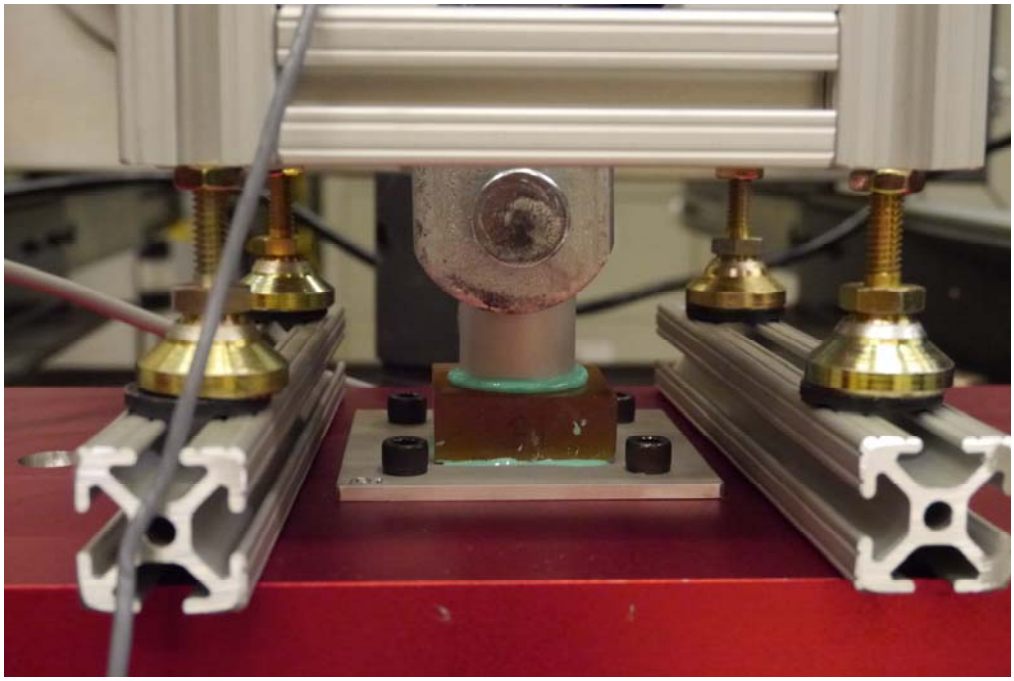

Figure 11. System Functional Test Setup

Two series of functional tests were performed, and each series consisted of 3 tests. The BTT and DAQ operated and functioned properly in all the functional tests. The adhesive bonding strength measurements from both series of tests are presented in Table 1, System Functional Test Data. In the first test series, the bonding strengths for all the samples were very low. The low bonding strength values were likely caused by using an old batch of adhesive and by the relatively rough tab surface finish that promoted subpar bonding. The second test series was done using a new batch of adhesive and with a finer, bead-blasted, surface finish on the tab. The first two test samples in the second series had high bonding strength of 428.3 psi and 580.6 psi. The last test sample, BTT-6, was misaligned during the bonding process, and the misalignment may have contributed to the low adhesive bonding strength measurement. The functional tests demonstrated that the test system was functional and that the tab bonding technique was sound.

Table 1 System Functional Test Data

Test ID	Test Series	Adhesive Bonding Strength (psi)
BTT-1	1	49.9
BTT-2		101.0
BTT-3		104.0
BTT-4	2	580.6
BTT-5		428.3
BTT-6		145.7

5.3 Button Tensile Testing

All the button tensile tests were conducted as a collaborative effort between NASA JSC CTSD and ATI. The concept of the test was developed jointly by the two organizations. The specimen preparation procedure was developed by CTSD, and the specimen preparations were carried out by ATI personnel. The preparation of test procedure, execution of the tests, and data analysis were performed by CTSD personnel. The detailed specimen preparation procedure, test procedure, and data analysis protocol are described in the following subsections.

5.3.1 Specimen Preparation

A button test specimen consists of a 1 inch diameter cylindrical 'button' cut from a clamp and a 1 inch diameter by 1.5 inch long cylindrical aluminum tab. The button was prepared by cutting through a clamp down to the surface of the test pipe using an electrical drill and hole-saw. The aluminum tab was machined from a 1 inch diameter aluminum bar stock and bonded to the 'button' with the Syntho-Subsea LV adhesive at ambient conditions. Each tab was machined with a 0.47 inches transverse through-hole for interfacing with the button tensile tester (BTT). A photograph showing the components of a button test specimen is included in Figure 12, Test Button and Test Tab. Each button specimen was cut from a specific location and labeled accordingly as indicated in section 5.1. The minimum distance between each specimen should be at least 2.5 inches as shown in Figure 13, Minimum Clearance between Specimens.

Figure 12. Test Button and Test Tab

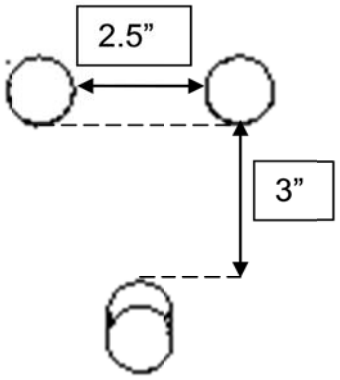

Figure 13. Minimum Clearance between Specimens

5.3.1.1 Button Cutting Procedure

Prior to cutting the polyurethane clamp to form a button specimen, the polyurethane surface was cleaned to remove any major contaminants (e.g. adhesive residuals) by sanding the surface with fine-grit sandpaper and wiping with acetone. A 1 inch diameter button specimen was prepared by cutting through a clamp, down to the pipe surface, with a 1-1/8 inch hole-saw and a hand-held electrical drill. The hole-saw was controlled to go through the clamp slowly until it made contact with the metal pipe surface. Precaution was taken to avoid applying excessive torque or side loading to the specimen that might weaken the epoxy bonding of the clamp with the pipe surface. During the cutting, the debris generated from the cutting operation was removed with a vacuum system.

5.3.1.2 Tab Bonding Procedure

After the button was cut, an aluminum tab was bonded with Syntho Subsea LV to the top surface of the button. Each tab was bonded per these instructions:

1. Make available a 1 inch diameter by 1.5 inch long tab with a 0.47 inches transverse through-hole, and the Syntho-Subsea LV two part epoxy.
2. Review all MSDS’s and safety procedure before continuing.
3. Clean the tab surface to be bonded to the button surface with acetone and allow it to air dry completely.
4. Clean the polyurethane button bonding surface by gently wiping it with acetone.
5. Make sure the epoxy components are at room temperature before mixing.
6. Mix thoroughly an equal amount of part A (white) and part B (Green) epoxy (1:1 volume ratio) with a mixing stick, on a clean disposal surface. The two parts are well mixed when the color of the mixture is uniform.
7. Apply a thin layer of adhesive to the cleaned button bonding surface or to the tab surface within 30 minutes of preparing the mixture. Make sure to apply enough adhesive to cover the whole surface of the tab. Verify that the tab and button are vertically aligned when bonding. Any excess of adhesive must be removed before it hardens.

8. Allow the adhesive to harden for at least 3 hours before rotating the pipe to prepare another set of buttons.
9. Allow the adhesive to cure for a minimum of 24 hours at room temperature prior to testing.
10. Label the test specimens/tabs with a unique ID number as described in section of 5.1 of this report.

5.3.2 Test Procedure

After the tabs were bonded and cured, the button specimens were ready for testing. The button tensile tests were performed as follows:

1. Prepare the BTT by plugging its power supply into an electrical outlet and connect the actuator and controller to the control box. Turn on the power supply and set the voltage to 20 V.
2. Plug-in the load cell to the data acquisition system, and turn on the computer.
3. Open the data acquisition program, set a data acquisition rate (100 Hz minimum), and activate the acquisition (but do not start logging data yet).
4. Set up the BTT over the test specimen and adjust the positioning feet to make sure the BTT is leveled and lined up with the tab of the specimen.
5. Insert a clevis pin through the transverse hole in the tab to connect the BTT and the tab. Secure the clevis pin with a cotter pin.
6. Hold down the top of the BTT to stabilize it during testing.
7. Verify that the data acquisition system is acquiring data. Name the test file to match the specimen ID number. Start recording data.
8. Press and hold the 'pull' button on the BTT controller to apply force to the specimen until the button breaks free from the pipe.
9. Stop logging data.
10. Record the specimen ID number, peak force, failure mode, and any comment on the data recording sheet.

5.3.3 Data Analysis

Data collected from each button tensile test included the time and force measurements, specimen failure type, adhesive failure mode, and the condition of the button's cylindrical cut. The time and force data were recorded by the DAQ, and the force vs. time curve was generated for each test. A typical force-vs.-time curve is shown in Figure 14, Button Tensile Test Force vs. Time Curve. For each valid test, the adhesive tensile strength (ATS) was calculated by dividing the peak force value by the nominal specimen surface area of 0.7854 in^2.

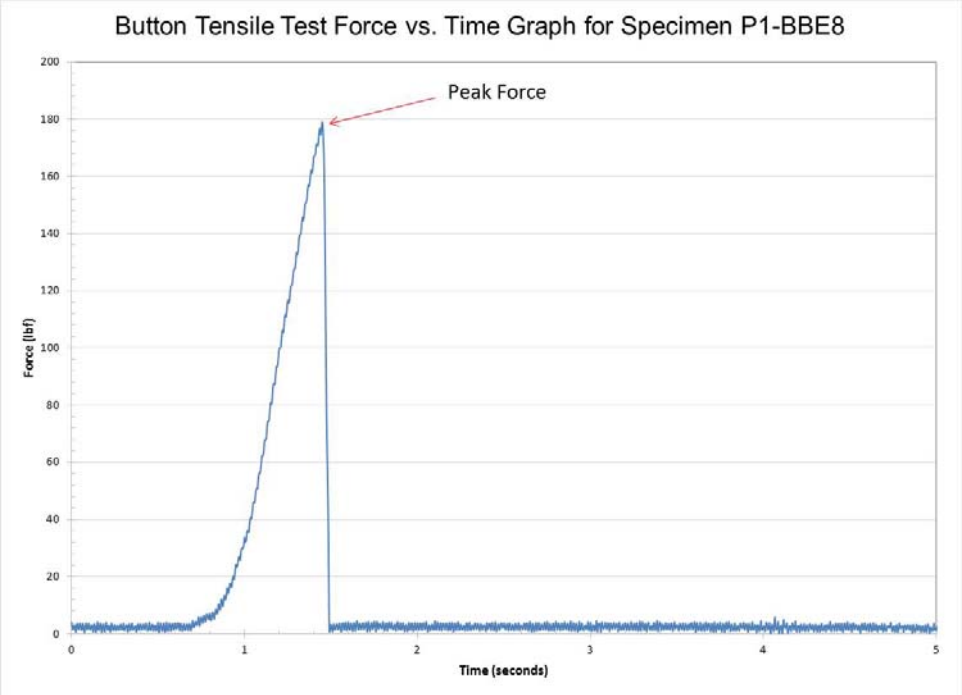

Figure 14. Button Tensile Test Force vs. Time Curve

5.3.3.1 Specimen Failure Types

There were two primary failure types: failure in the bonding interface between the tab and the button (tab/button failure) and failure in the bonding interface between the button and the pipe (button/pipe failure). In some instances, the failure occurred simultaneously at the Tab/Button and Button/Pipe interfaces. The data from Tab/Button failures were discarded because they were not relevant to the evaluation of the bonding strength of the adhesive between the clamp and the pipe. As the team gained more experience at performing these tests, the tab bonding technique improved, and the frequency of tab/button failure decreased significantly. The lessons learned concerning the specimen preparation and tab bonding techniques are included in section 7.0 of this report.

5.3.3.2 Adhesive Failure Modes

Three different modes of adhesive failure were observed: failure (de-bonding) on the PU surface, failure on the steel pipe surface, and mixed mode failure. These modes of failure are illustrated in Figure 15, Post-Test Photographs of Different Adhesive Failure Modes. The mode of failure was documented with a numerical value expressed in percentage of adhesive remaining on the polyurethane surface. A value of 0 % adhesive on polyurethane was classified as adhesive failure on the PU surface. A value of 100 % adhesive on polyurethane was classified as adhesive failure on the steel pipe surface. Values between 0 % and 100 % were classified as mixed mode failure.

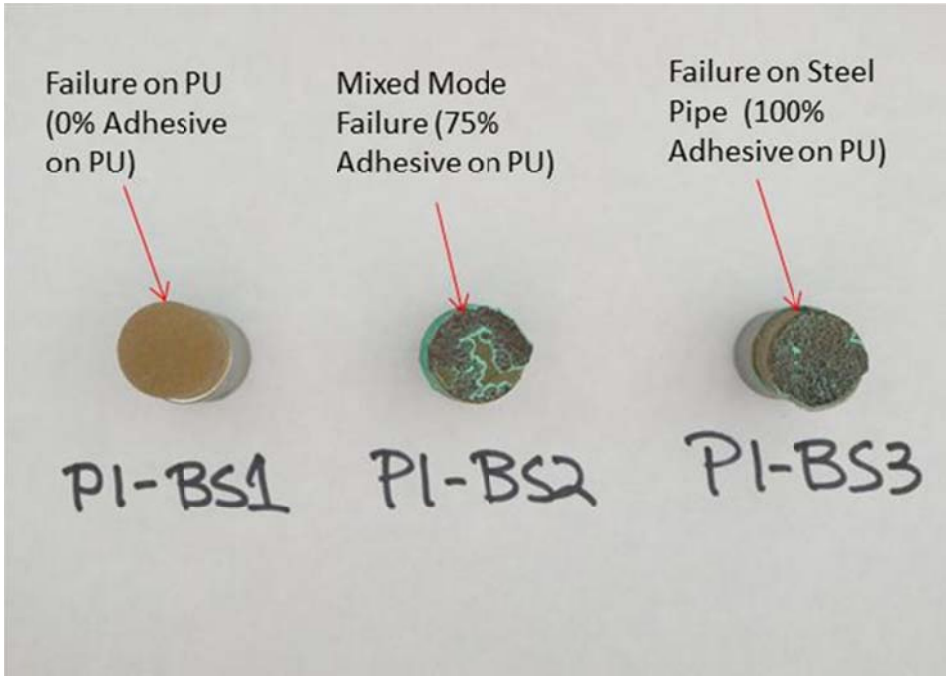

Figure 15. Post Test Photographs of Different Adhesive Failure Modes

5.3.3.3 Specimen Cut Conditions

During the course of the study, it was found that some of the buttons had not been completely cut by the hole-saw through the clamp adhesive down to the pipe. The extent of cut was called "cut condition". A photograph comparing the edges of a perfectly cut specimen and a partially cut specimen are shown in Figure 16, Button Specimen Cut Conditions. Each specimen was visually inspected to determine its cut condition. Then, a numerical value was given to the button as a percentage of the area cut down to the pipe surface. A specimen with less than 100 % cut through was treated separately to determine if the data from the button tensile test of this specimen were useable.

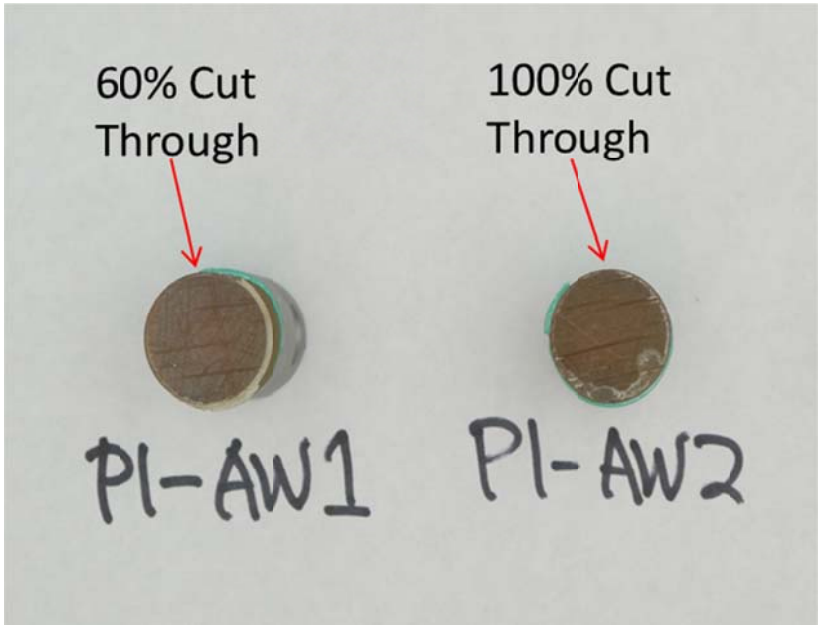

Figure 16. Button Specimen Cut Conditions

5.3.3.4 Force Time Response Analysis

After determining the specimen cut condition, a force time response analysis (FTRA) was performed to determine if the test with a partially cut specimen produced valid ATS data. The FTRA examined the slope of the force-vs.-time curve to determine if the failure was that of the adhesive bonded to the pipe alone or that of the uncut polyurethane. Because of the non-elastic nature of the rigid epoxy bond, the loading curve of the adhesive had a steep slope. On the other hand, the slope of the loading curve of the polyurethane was not as steep because of the elastic nature of the material. The force-vs.-time curves of all the specimens were plotted and analyzed to determine the validity of the test results and the corresponding ATS.

The force-vs.-time curves of three specimens with different cut conditions and loading responses are shown in Figure 17, Force Time Response Analysis (FTRA). The first curve (blue) for specimen P1-BBE8, which was 100 % cut, showed a typical adhesive loading response with a steep slope. The peak force from the curve represents the load required to break the adhesive bond of the specimen. The second curve (red) for specimen P1-BN8, which was only 40 % cut, showed a typical polyurethane loading response with a gentle slope. The data described the breaking of the still attached polyurethane and did not represent the breaking of the adhesive bond. Therefore, the data for P1-BN8 were considered invalid. The third curve (green) for specimen P1-CN4, which was also only 40 % cut, showed a mixed adhesive and polyurethane response. The first part of the (steeply sloped) curve represented the initial loading and breaking of the adhesive bond. The second part of the (gently sloped) curve described the loading and breaking of the polyurethane specimen edge that was still attached to the parent material. Since the adhesive loading and breaking response was sufficiently captured, the peak force from the first part of the curve was used to calculate the ATS of the specimen.

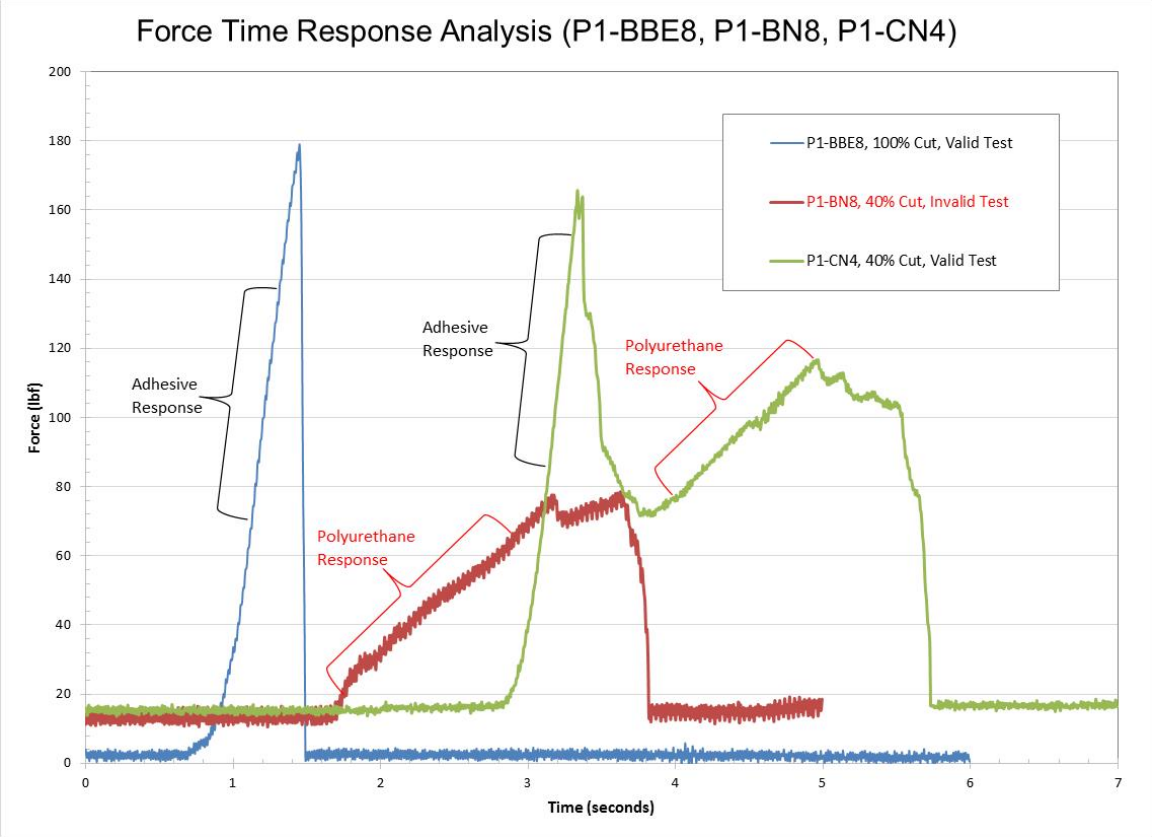

Figure 17. Force Time Response Analysis (FTRA)

6.0 Test Results and Findings

The results and findings from the button tensile tests for each test clamp are documented in the following subsections. The results for each clamp are presented in a table, which includes the test specimen ID, adhesive tensile strength, test failure type, adhesive failure mode, and specimen cut condition. All the valid test results are colored in black. The invalid test results due to the Tab/Button failure are colored in blue. The test results determined invalid from the FTRA are colored in red. All the photographs of the specimens and clamps before testing are included in Appendix B, Before Test Photographs, for reference. The after test photographs are included in Appendix C, After Test Photographs, for reference.

6.1 Pipe P1 Clamp A

Clamp A was the first clamp to be installed by a diver on the 13' pipe. According to ATI, the pipe surface had not been cleaned properly for the installation of this clamp. Hence, the bonding conditions were not optimal.

The test results for Clamp A are presented in Table 2, Pipe P1 Clamp A Button Tensile Test Results. An average ATS of 94.0 psi and a standard deviation of 30.4 psi were calculated for a total of 20 valid tests. The average ATS of Clamp A is the second lowest average value for all the clamps installed by a diver. Highest and lowest ATS values are 155.8 psi and 45.0 psi. The predominant adhesive failure mode for clamp A is failure on the PU surface.

Table 2. Pipe P1 Clamp A Button Tensile Test Results

Specimen ID	Adhesive Tensile Strength (psi)	Failure Type	Adhesive Failure Mode[1]	Specimen Cut Condition[2]
P1-AN1	125.9	Button/Pipe	0% Adhesive on Polyurethane	70%
P1-AN2	75.7	Button/Pipe	100% Adhesive on Polyurethane	100%
P1-AN3	123.8	Button/Pipe	0% Adhesive on Polyurethane	100%
P1-AN4	77.5	Tab/Button	N/A	N/A
P1-AN5	45.0	Button/Pipe	100% Adhesive on Polyurethane	100%
P1-AN6	104.6	Button/Pipe	0% Adhesive on Polyurethane	80%
P1-AE1	116.1	Tab/Button/Pipe	N/A	N/A
P1-AE2	104.2	Button/Pipe	0% Adhesive on Polyurethane	100%
P1-AE4	72.9	Button/Pipe	0% Adhesive on Polyurethane	70%
P1-AS1	133.8	Tab/Button	N/A	N/A
P1-AS2	54.0	Button/Pipe	0% Adhesive on Polyurethane	40%
P1-AS3	67.7	Button/Pipe	0% Adhesive on Polyurethane	40%
P1-AS4	76.2	Tab/Button/Pipe	0% Adhesive on Polyurethane	40%
P1-AS5	105.9	Button/Pipe	0% Adhesive on Polyurethane	100%
P1-AS6	89.9	Button/Pipe	0% Adhesive on Polyurethane	100%
P1-AS7	47.0	Button/Pipe	0% Adhesive on Polyurethane	50%
P1-AS8	145.7	Button/Pipe	0% Adhesive on Polyurethane	50%
P1-AW1	87.0	Button/Pipe	0% Adhesive on Polyurethane	60%
P1-AW2	83.8	Button/Pipe	0% Adhesive on Polyurethane	100%
P1-AW3	104.9	Button/Pipe	100% Adhesive on Polyurethane	100%
P1-AW4	92.8	Button/Pipe	0% Adhesive on Polyurethane	100%
P1-AW5	155.8	Button/Pipe	0% Adhesive on Polyurethane	100%
P1-AW6	20.3	Button/Pipe	0% Adhesive on Polyurethane	70%

[1] The definition of this term is detailed in section 5.3.3.2
[2] The definition of this term is detailed in section 5.3.3.3

6.2 Pipe P1 Clamp B

Clamp B on Pipe P1 was also one of the seven clamps installed by a diver during the ATI clamp installation test. According to ATI, this was the best installed clamp. The test results for Clamp B are presented in Table 3, Pipe P1 Clamp B Button Tensile Test Results. An average ATS of 174.1 psi and a standard deviation of 112.4 psi were calculated for a total of 24 valid tests. Clamp B has the highest average ATS out of all the clamps installed by a diver. Highest and lowest ATS values are 503.3 psi and 29.8 psi. Most of the specimens from Clamp B failed on the steel pipe surface. However, 10 specimens failed in a mixed mode.

Table 3. Pipe P1 Clamp B Button Tensile Test Results

Specimen ID	Adhesive Tensile Strength (psi)	Failure Type	Adhesive Failure Mode[3]	Specimen Cut Condition[4]
P1-BN1	112.3	Tab/Button	N/A	N/A
P1-BN2	139.4	Button/Pipe	95% Adhesive on Polyurethane	100%
P1-BN3	132.2	Tab/Button	N/A	N/A
P1-BN4	112.5	Tab/Button	100% Adhesive on Polyurethane	50%
P1-BN5	204.1	Button/Pipe	40% Adhesive on Polyurethane	60%
P1-BN6	89.2	Button/Pipe	70% Adhesive on Polyurethane	40%
P1-BN7	86.9	Tab/Button	100% Adhesive on Polyurethane	100%
P1-BN8	83.3	Button/Pipe	100% Adhesive on Polyurethane	40%
P1-BN9	33.0	Tab/Button	60% Adhesive on Polyurethane	100%
P1-BN10	68.4	Tab/Button	N/A	N/A
P1-BE1	309.6	Button/Pipe	70% Adhesive on Polyurethane	50%
P1-BE3	161.3	Tab/Button	N/A	N/A
P1-BE4	113.7	Tab/Button	N/A	N/A
P1-BE5	29.8	Button/Pipe	100% Adhesive on Polyurethane	60%
P1-BE6	111.7	Tab/Button	N/A	N/A
P1-BE7	283.3	Button/Pipe	45% Adhesive on Polyurethane	70%
P1-BE8	175.0	Button/Pipe	100% Adhesive on Polyurethane	100%
P1-BE9	128.3	Button/Pipe	100% Adhesive on Polyurethane	100%

[3] The definition of this term is detailed in section 5.3.3.2
[4] The definition of this term is detailed in section 5.3.3.3

Specimen ID	Adhesive Tensile Strength (psi)	Failure Type	Adhesive Failure Mode[3]	Specimen Cut Condition[4]
P1-BE10	249.1	Tab/Button	N/A	N/A
P1-BS1	503.3	Tab/Button/Pipe	0% Adhesive on Polyurethane	100%
P1-BS2	192.8	Button/Pipe	75% Adhesive on Polyurethane	100%
P1-BS3	150.3	Button/Pipe	98% Adhesive on Polyurethane	70%
P1-BS4	190.4	Tab/Button	60% Adhesive on Polyurethane	100%
P1-BS5	162.8	Button/Pipe	100% Adhesive on Polyurethane	100%
P1-BS6	80.1	Button/Pipe	100% Adhesive on Polyurethane	100%
P1-BS7	164.9	Button/Pipe	100% Adhesive on Polyurethane	100%
P1-BS8	350.9	Button/Pipe	80% Adhesive on Polyurethane	100%
P1-BS9	329.8	Button/Pipe	40% Adhesive on Polyurethane	80%
P1-BS10	36.9	Button/Pipe	100% Adhesive on Polyurethane	70%
P1-BW1	112.1	Button/Pipe	100% Adhesive on Polyurethane	100%
P1-BW2	134.9	Button/Pipe	100% Adhesive on Polyurethane	100%
P1-BW3	57.7	Button/Pipe	100% Adhesive on Polyurethane	70%
P1-BW4	44.7	Button/Pipe	100% Adhesive on Polyurethane	N/A
P1-BW5	77.0	Button/Pipe	100% Adhesive on Polyurethane	100%
P1-BW6	164.2	Button/Pipe	95% Adhesive on Polyurethane	100%
P1-BW7	206.3	Button/Pipe	100% Adhesive on Polyurethane	100%
P1-BW8	96.2	Button/Pipe	100% Adhesive on Polyurethane	100%

[3] The definition of this term is detailed in section 5.3.3.2
[4] The definition of this term is detailed in section 5.3.3.3

6.3 Pipe P1 Clamp AA

Clamp AA, used as a control, was installed on pipe P1 inside a box filled with tap water at the ATI facility. ATI reported that the clamp had not been properly installed. The time elapsed between preparation of the adhesive and its application on the clamp was longer than its recommended pot life.

The test results for Clamp AA are presented in Table 4, Pipe P1 Clamp AA Button Tensile Test Results. An average ATS of 81.4 psi and a standard deviation of 47.2 psi were calculated for a total of 13 valid tests. The average ATS for clamp AA is the lowest in this study. Highest and lowest ATS values are 193.5 psi and 31.1 psi. The predominant failure mode for clamp AA is failure on the steel pipe surface. The improper installation of the clamp likely contributed to the low ATS test result.

Table 4. Pipe P1 Clamp AA Button Tensile Test Results

Specimen ID	Adhesive Tensile Strength (psi)	Failure Type	Adhesive Failure Mode[5]	Specimen Cut Condition[6]
P1-AAN1	52.5	Tab/Button	N/A	N/A
P1-AAN2	94.2	Tab/Button	N/A	N/A
P1-AAN3	77.1	Tab/Button	N/A	N/A
P1-AAN4	95.7	Button/Pipe	100% Adhesive on Polyurethane	50%
P1-AAN5	66.2	Button/Pipe	100% Adhesive on Polyurethane	60%
P1-AAN6	66.3	Button/Pipe	100% Adhesive on Polyurethane	50%
P1-AAE1	70.1	Tab/Button	N/A	N/A
P1-AAE2	93.3	Tab/Button	N/A	N/A
P1-AAE3	57.4	Tab/Button	N/A	N/A
P1-AAE4	65.0	Tab/Button	N/A	N/A
P1-AAE5	21.7	Tab/Button	N/A	N/A
P1-AAE6	131.3	Button/Pipe	80% Adhesive on Polyurethane	100%
P1-AAE7	193.5	Button/Pipe	90% Adhesive on Polyurethane	100%
P1-AAE8	123.9	Button/Pipe	80% Adhesive on Polyurethane	80%
P1-AAS1	48.9	Tab/Button	N/A	N/A
P1-AAS2	76.9	Tab/Button	N/A	N/A
P1-AAS4	99.9	Button/Pipe	100% Adhesive on Polyurethane	100%
P1-AAW1	31.1	Button/Pipe	100% Adhesive on Polyurethane	80%
P1-AAW2	36.6	Button/Pipe	100% Adhesive on Polyurethane	70%
P1-AAW3	44.0	Button/Pipe	95% Adhesive on Polyurethane	40%
P1-AAW4	79.6	Button/Pipe	95% Adhesive on Polyurethane	40%
P1-AAW5	356.8	Tab/Button	N/A	N/A
P1-AAW6	33.9	Button/Pipe	100% Adhesive on Polyurethane	60%
P1-AAW7	26.6	Button/Pipe	100% Adhesive on Polyurethane	70%

[5] The definition of this term is detailed in section 5.3.3.2
[6] The definition of this term is detailed in section 5.3.3.3

Specimen ID	Adhesive Tensile Strength (psi)	Failure Type	Adhesive Failure Mode[5]	Specimen Cut Condition[6]
P1-AAW8	55.8	Button/Pipe	95% Adhesive on Polyurethane	30%

[5] The definition of this term is detailed in section 5.3.3.2
[6] The definition of this term is detailed in section 5.3.3.3

6.4 Pipe P1 Clamp E

Clamp E was another clamp installed on the 13' pipe by a diver. This is one of the two clamps that contain sensors and wiring. This clamp, located at the center of the pipe, had been subjected to the highest bending stresses during the post installation load-tests. Because of the presence of the embedded sensors and wiring, specimen cutting was restricted to a certain area. More buttons were prematurely separated from the pipe during cutting than for any other clamp in this study. As a result, only a few specimens were successfully prepared.

The test results for Clamp E are presented in Table 5, Pipe P1 Clamp E Button Tensile Test Results. Only 4 valid tests were completed. The average ATS is 91.1 psi and the standard deviation is 46.9 psi. Clamp E has the lowest average ATS value among all the diver's installed clamps in this study. Highest and lowest ATS are 150.8 psi and 49.5 psi. The predominant adhesive failure mode for clamp E is failure on the PU surface.

Table 5. Pipe P1 Clamp E Button Tensile Test Results

Specimen ID	Adhesive Tensile Strength (psi)	Failure Type	Adhesive Failure Mode[7]	Specimen Cut Condition[8]
P1-EE1	105.9	Button/Pipe	0% Adhesive on Polyurethane	80%
P1-EE2	57.9	Button/Pipe	0% Adhesive on Polyurethane	60%
P1-EE3	150.8	Button/Pipe	2% Adhesive on Polyurethane	100%
P1-EE4	58.3	Button/Pipe	0% Adhesive on Polyurethane	100%
P1-ES1	49.5	Button/Pipe	0% Adhesive on Polyurethane	70%
P1-ES2	52.6	Button/Pipe	0% Adhesive on Polyurethane	40%
P1-ES3	217.0	Tab/Button	N/A	N/A

[7] The definition of this term is detailed in section 5.3.3.2
[8] The definition of this term is detailed in section 5.3.3.3

6.5 Pipe P1 Clamp BB

Clamp BB on Pipe P1 is another control sample. It was installed on a well-cleaned surface at ambient (dry) conditions in the ATI workshop facility. Hence, this clamp can be used for reference in comparing the adhesive bonding strengths between all the clamps tested in the study.

The test results for Clamp BB are presented in Table 6, Pipe P1 Clamp BB Button Tensile Test Results. A total of 18 tests were valid. The average ATS of all the valid tests is 292.0 psi and the corresponding standard deviation is 108.9 psi. Clamp BB has the highest average ATS value among all the clamps tested in this study. The highest and lowest measured ATS are 498.6 psi and 113.6 psi. Most of the valid test specimens failed in mixed mode failure.

Table 6. Pipe P1 Clamp BB Button Tensile Test Results

Specimen ID	Adhesive Tensile Strength (psi)	Failure Type	Adhesive Failure Mode[9]	Specimen Cut Condition[10]
P1-BBN1	409.7	Button/Pipe	0% Adhesive on Polyurethane	100%
P1-BBN2	378.2	Button/Pipe	10% Adhesive on Polyurethane	100%
P1-BBN3	130.6	Tab/Button	N/A	N/A
P1-BBN4	255.4	Tab/Button	N/A	N/A
P1-BBN5	239.6	Tab/Button	N/A	N/A
P1-BBN6	106.6	Tab/Button	N/A	N/A
P1-BBN7	186.1	Button/Pipe	40% Adhesive on Polyurethane	60%
P1-BBN8	264.6	Button/Pipe	30% Adhesive on Polyurethane	60%
P1-BBE1	13.7	Tab/Button	N/A	N/A
P1-BBE2	236.2	Tab/Button	N/A	N/A
P1-BBE3	357.2	Tab/Button	N/A	N/A
P1-BBE4	145.7	Tab/Button	N/A	N/A
P1-BBE6	33.9	Tab/Button	N/A	N/A
P1-BBE7	359.5	Tab/Button	N/A	N/A
P1-BBE8	224.6	Button/Pipe	40% Adhesive on Polyurethane	100%
P1-BBE9	265.1	Button/Pipe	30% Adhesive on Polyurethane	100%
P1-BBE10	237.8	Button/Pipe	50% Adhesive on Polyurethane	100%
P1-BBS1	237.0	Tab/Button	N/A	N/A

[9] The definition of this term is detailed in section 5.3.3.2
[10] The definition of this term is detailed in section 5.3.3.3

Specimen ID	Adhesive Tensile Strength (psi)	Failure Type	Adhesive Failure Mode[9]	Specimen Cut Condition[10]
P1-BBS2	80.6	Tab/Button	N/A	N/A
P1-BBS3	116.9	Tab/Button	N/A	N/A
P1-BBS4	157.8	Tab/Button	N/A	N/A
P1-BBS5	322.2	Button/Pipe	20% Adhesive on Polyurethane	100%
P1-BBS6	127.8	Tab/Button	N/A	N/A
P1-BBS7	210.5	Tab/Button	N/A	N/A
P1-BBS8	223.9	Tab/Button	N/A	N/A
P1-BBS9	498.6	Button/Pipe	80% Adhesive on Polyurethane	100%
P1-BBS13	175.0	Button/Pipe	30% Adhesive on Polyurethane	100%
P1-BBS14	113.6	Button/Pipe	70% Adhesive on Polyurethane	100%
P1-BBS15	132.1	Button/Pipe	80% Adhesive on Polyurethane	100%
P1-BBW1	389.7	Button/Pipe	0% Adhesive on Polyurethane	100%
P1-BBW2	234.6	Button/Pipe	0% Adhesive on Polyurethane	100%
P1-BBW3	452.8	Button/Pipe	5% Adhesive on Polyurethane	70%
P1-BBW4	280.1	Button/Pipe	10% Adhesive on Polyurethane	90%
P1-BBW5	363.2	Button/Pipe	5% Adhesive on Polyurethane	100%
P1-BBW6	328.9	Button/Pipe	20% Adhesive on Polyurethane	100%

[9] The definition of this term is detailed in section 5.3.3.2
[10] The definition of this term is detailed in section 5.3.3.3

6.6 Pipe P1 Clamp C

Clamp C was also installed on the 13' pipe by a diver. According to ATI, the pipe surface cleaning and the clamp installation were properly done.

The test results for Clamp C are presented in Table 7, Pipe P1 Clamp C Button Tensile Test Results. A total of 18 tests were valid. The average ATS of all the valid tests is 142.5 psi and the corresponding standard deviation is 66.6 psi. The highest and lowest measured ATS are 267.9 psi and 45.8 psi. The predominant adhesive failure mode for Clamp C specimens is mixed mode failure.

Table 7. Pipe P1 Clamp C Button Tensile Test Results

Specimen ID	Adhesive Tensile Strength (psi)	Failure Type	Adhesive Failure Mode[11]	Specimen Cut Condition[12]
P1-CN1	113.8	Tab/Button	N/A	N/A
P1-CN2	132.7	Button/Pipe	95% Adhesive on Polyurethane	40%
P1-CN3	99.4	Tab/Button	N/A	N/A
P1-CN4	191.2	Button/Pipe	60% Adhesive on Polyurethane	40%
P1-CN5	57.0	Button/Pipe	90% Adhesive on Polyurethane	50%
P1-CN6	82.8	Button/Pipe	100% Adhesive on Polyurethane	40%
P1-CE1	135.9	Tab/Button	N/A	N/A
P1-CE2	159.6	Tab/Button	N/A	N/A
P1-CE3	109.4	Tab/Button	N/A	N/A
P1-CE4	118.4	Button/Pipe	50% Adhesive on Polyurethane	60%
P1-CE5	96.4	Tab/Button	N/A	N/A
P1-CE6	93.1	Button/Pipe	40% Adhesive on Polyurethane	40%
P1-CE7	164.5	Button/Pipe	80% Adhesive on Polyurethane	100%
P1-CE8	85.2	Button/Pipe	80% Adhesive on Polyurethane	100%
P1-CE9	237.7	Button/Pipe	70% Adhesive on Polyurethane	100%
P1-CE10	188.7	Button/Pipe	80% Adhesive on Polyurethane	100%
P1-CS2	45.8	Button/Pipe	0% Adhesive on Polyurethane	100%
P1-CS3	165.9	Button/Pipe	2% Adhesive on Polyurethane	100%
P1-CS4	185.6	Button/Pipe	50% Adhesive on Polyurethane	100%
P1-CS5	184.6	Button/Pipe	0% Adhesive on Polyurethane	70%
P1-CW1	68.8	Tab/Button	N/A	N/A
P1-CW2	57.0	Tab/Button	N/A	N/A
P1-CW3	39.8	Tab/Button	N/A	N/A
P1-CW4	153.0	Tab/Button	N/A	N/A

[11] The definition of this term is detailed in section 5.3.3.2
[12] The definition of this term is detailed in section 5.3.3.3

Specimen ID	Adhesive Tensile Strength (psi)	Failure Type	Adhesive Failure Mode[11]	Specimen Cut Condition[12]
P1-CW5	578.1	Tab/Button	N/A	N/A
P1-CW6	164.6	Button/Pipe	50% Adhesive on Polyurethane	60%
P1-CW7	267.9	Button/Pipe	30% Adhesive on Polyurethane	45%
P1-CW8	85.4	Button/Pipe	85% Adhesive on Polyurethane	100%
P1-CW9	201.1	Tab/Button	N\A	N/A
P1-CW10	59.2	Button/Pipe	10% Adhesive on Polyurethane	90%
P1-CW11	188.1	Button/Pipe	70% Adhesive on Polyurethane	60%

[11] The definition of this term is detailed in section 5.3.3.2
[12] The definition of this term is detailed in section 5.3.3.3

6.7 Pipe P1 Clamp D

Clamp D on pipe P1 was one of the seven clamps installed by a diver during the ATI clamp installation test. According to ATI, the pipe surface cleaning and the clamp installation were properly done.

The test results for Clamp D are presented in Table 8, Pipe P1 Clamp D Button Tensile Test Results. A total of 15 tests were valid. The average ATS of all the valid tests is 136.3 psi and the standard deviation is 73.6 psi. The highest and lowest measured ATS are 358.7 psi and 57.5 psi. Eight valid test specimens failed on the steel pipe surface. The other seven failed in mixed mode.

Table 8. Pipe P1 Clamp D Button Tensile Test Results

Specimen ID	Adhesive Tensile Strength (psi)	Failure Type	Adhesive Failure Mode[13]	Specimen Cut Condition[14]
P1-DN1	135.6	Tab/Button/Pipe	90% Adhesive on Polyurethane	40%
P1-DN2	138.5	Button/Pipe	90% Adhesive on Polyurethane	50%
P1-DN3	137.5	Button/Pipe	95% Adhesive on Polyurethane	50%
P1-DN4	158.4	Tab/Button	N/A	N/A
P1-DN5	152.9	Tab/Button	N/A	N/A
P1-DN6	67.8	Tab/Button	N/A	N/A
P1-DN7	181.0	Tab/Button	N/A	N/A

[13] The definition of this term is detailed in section 5.3.3.2
[14] The definition of this term is detailed in section 5.3.3.3

Specimen ID	Adhesive Tensile Strength (psi)	Failure Type	Adhesive Failure Mode[13]	Specimen Cut Condition[14]
P1-DN8	229.3	Button/Pipe	40% Adhesive on Polyurethane	100%
P1-DN9	284.8	Tab/Button	N/A	N/A
P1-DN10	84.3	Tab/Button	N/A	N/A
P1-DN11	100.7	Tab/Button	N/A	N/A
P1-DE2	57.0	Tab/Button	60% Adhesive on Polyurethane	70%
P1-DE3	120.5	Button/Pipe	100% Adhesive on Polyurethane	100%
P1-DE4	133.7	Button/Pipe	100% Adhesive on Polyurethane	100%
P1-DE6	105.1	Button/Pipe	100% Adhesive on Polyurethane	100%
P1-DS1	91.1	Tab/Button	N/A	N/A
P1-DS2	358.7	Button/Pipe	55% Adhesive on Polyurethane	60%
P1-DS3	232.8	Tab/Button	N/A	N/A
P1-DS4	56.0	Tab/Button	N/A	N/A
P1-DS5	66.4	Button/Pipe	100% Adhesive on Polyurethane	100%
P1-DS6	99.0	Button/Pipe	100% Adhesive on Polyurethane	100%
P1-DS7	145.4	Button/Pipe	100% Adhesive on Polyurethane	50%
P1-DW1	24.4	Tab/Button	N/A	N/A
P1-DW2	118.1	Button/Pipe	100% Adhesive on Polyurethane	50%
P1-DW3	99.0	Tab/Button	N/A	N/A
P1-DW4	145.6	Button/Pipe	90% Adhesive on Polyurethane	50%
P1-DW5	18.3	Button/Pipe	100% Adhesive on Polyurethane	50%
P1-DW6	57.5	Button/Pipe	100% Adhesive on Polyurethane	100%
P1-DW7	122.3	Button/Pipe	70% Adhesive on Polyurethane	70%
P1-DW8	77.6	Button/Pipe	98% Adhesive on Polyurethane	70%

[13] The definition of this term is detailed in section 5.3.3.2
[14] The definition of this term is detailed in section 5.3.3.3

6.8 Pipe P2 Clamp F

Clamp F was installed on the 5' pipe, P2, by a diver during the ATI clamp installation test. According to ATI, the pipe surface cleaning and the clamp installation were properly done.

The test results for Clamp F on pipe P2 are presented in Table 9, Pipe P2 Clamp F Button Tensile Test Results. A total of 15 tests were valid. The average ATS of all the valid tests is 114.5 psi, and the corresponding standard deviation is 53.7 psi. The highest and lowest measured ATS are 225.7 psi and 33.6 psi. The predominant mode of failure for specimens from Clamp F was mixed mode failure.

Table 9. Pipe P2 Clamp F Button Tensile Test Results

Specimen ID	Adhesive Tensile Strength (psi)	Failure Type	Adhesive Failure Mode[15]	Specimen Cut Condition[16]
P2-FN1	57.5	Button/Pipe	0% Adhesive on Polyurethane	40%
P2-FN2	33.6	Button/Pipe	0% Adhesive on Polyurethane	90%
P2-FN3	100.5	Button/Pipe	0% Adhesive on Polyurethane	60%
P2-FN4	141.8	Tab/Button	N/A	N/A
P2-FN5	101.8	Button/Pipe	80% Adhesive on Polyurethane	40%
P2-FE1	132.6	Button/Pipe	70% Adhesive on Polyurethane	100%
P2-FE2	225.7	Button/Pipe	0% Adhesive on Polyurethane	60%
P2-FE3	116.3	Tab/Button	N/A	N/A
P2-FE4	52.0	Button/Pipe	10% Adhesive on Polyurethane	100%
P2-FE5	159.2	Button/Pipe	20% Adhesive on Polyurethane	100%
P2-FS1	23.3	Button/Pipe	100% Adhesive on Polyurethane	100%
P2-FS2	110.5	Button/Pipe	80% Adhesive on Polyurethane	100%
P2-FS3	205.6	Button/Pipe	98% Adhesive on Polyurethane	100%
P2-FS4	98.3	Button/Pipe	90% Adhesive on Polyurethane	100%
P2-FS5	144.0	Button/Pipe	98% Adhesive on Polyurethane	100%
P2-FW1	123.2	Button/Pipe	100% Adhesive on Polyurethane	100%
P2-FW2	104.3	Button/Pipe	50% Adhesive on Polyurethane	100%
P2-FW3	82.2	Button/Pipe	90% Adhesive on Polyurethane	60%
P2-FW4	288.9	Tab/Button/Pipe	5% Adhesive on Polyurethane	10%

[15] The definition of this term is detailed in section 5.3.3.2
[16] The definition of this term is detailed in section 5.3.3.3

Specimen ID	Adhesive Tensile Strength (psi)	Failure Type	Adhesive Failure Mode[15]	Specimen Cut Condition[16]
P2-FW5	114.1	Button/Pipe	95% Adhesive on Polyurethane	80%
P2-FW6	20.0	Button/Pipe	95% Adhesive on Polyurethane	50%
P2-FW7	81.3	Button/Pipe	95% Adhesive on Polyurethane	60%

[15] The definition of this term is detailed in section 5.3.3.2
[16] The definition of this term is detailed in section 5.3.3.3

6.9 Pipe P3 Clamp G

Clamp G was installed onto pipe P3 by a diver during the ATI clamp installation test. This is one of the two clamps with sensors and wiring embedded into the clamp. According to ATI, the pipe surfaces cleaning and the clamp installation were properly done.

The test results for Clamp G on pipe P3 are presented in Table 10, Pipe P3 Clamp G Button Tensile Test Results. A total of 15 tests were valid. The average ATS of all the valid tests is 105.3 psi and the corresponding standard deviation is 59.8 psi. The highest and lowest measured ATS are 268.8 psi and 29.7 psi. The predominant adhesive failure mode for clamp G specimens is failure on the PU surface.

Table 10. Pipe P3 Clamp G Button Tensile Test Results

Specimen ID	Adhesive Tensile Strength (psi)	Failure Type	Adhesive Failure Mode[17]	Specimen Cut Condition[18]
P3-GN1	31.2	Button/Pipe	0% Adhesive on Polyurethane	99%
P3-GN2	18.0	Button/Pipe	0% Adhesive on Polyurethane	100%
P3-GN3	51.6	Button/Pipe	0% Adhesive on Polyurethane	10%
P3-GN4	154.9	Button/Pipe	0% Adhesive on Polyurethane	40%
P3-GE1	67.6	Button/Pipe	0% Adhesive on Polyurethane	40%
P3-GE2	119.0	Button/Pipe	0% Adhesive on Polyurethane	30%
P3-GE3	63.3	Button/Pipe	0% Adhesive on Polyurethane	40%
P3-GE4	93.7	Button/Pipe	0% Adhesive on Polyurethane	50%
P3-GE5	132.7	Button/Pipe	0% Adhesive on Polyurethane	60%
P3-GE6	56.0	Button/Pipe	90% Adhesive on Polyurethane	100%
P3-GE7	124.4	Button/Pipe	2% Adhesive on Polyurethane	100%

[17] The definition of this term is detailed in section 5.3.3.2
[18] The definition of this term is detailed in section 5.3.3.3

Specimen ID	Adhesive Tensile Strength (psi)	Failure Type	Adhesive Failure Mode[17]	Specimen Cut Condition[18]
P3-GE8	39.2	Tab/Button	N/A	N/A
P3-GE9	86.0	Button/Pipe	2% Adhesive on Polyurethane	95%
P3-GS1	52.3	Button/Pipe	0% Adhesive on Polyurethane	30%
P3-GS2	34.9	Button/Pipe	0% Adhesive on Polyurethane	20%
P3-GS3	110.8	Button/Pipe	0% Adhesive on Polyurethane	100%
P3-GS4	85.3	Button/Pipe	0% Adhesive on Polyurethane	0%
P3-GS5	79.6	Button/Pipe	0% Adhesive on Polyurethane	95%
P3-GS6	103.6	Button/Pipe	0% Adhesive on Polyurethane	40%
P3-GS7	82.3	Button/Pipe	5% Adhesive on Polyurethane	60%
P3-GS8	113.7	Button/Pipe	0% Adhesive on Polyurethane	10%
P3-GS9	324.2	Tab/Button	N/A	N/A
P3-GS10	154.9	Tab/Button	N/A	N/A
P3-GS11	147.7	Tab/Button	N/A	N/A
P3-GW1	157.1	Button/Pipe	40% Adhesive on Polyurethane	95%
P3-GW2	142.3	Tab/Button	N/A	N/A
P3-GW3	29.7	Button/Pipe	70% Adhesive on Polyurethane	70%
P3-GW4	268.8	Button/Pipe	2% Adhesive on Polyurethane	50%
P3-GW5	99.6	Button/Pipe	30% Adhesive on Polyurethane	30%

[17] The definition of this term is detailed in section 5.3.3.2
[18] The definition of this term is detailed in section 5.3.3.3

7.0 Summary and Discussion

A total of 239 button tensile tests were conducted in this study. One hundred and forty-two (142) of these tests produced valid data that were useful to determine how well the various clamps were bonded to the test pipes. The summary button tensile test results for all the clamps are presented in Table 11, Button Tensile Test Result Summary for Pipe P1, and Table 12, Button Tensile Test Result Summary for Pipes P2 and P3. The average ATS for all the diver-installed clamps range from 91.1 psi to 174.1 psi. The ATS standard deviations of these clamps range from 30.4 psi to 112.4 psi. The broad range of average ATS values and large standard deviation values can essentially be attributed to differences in installation preparations and techniques. Since the clamps were installed during the ATI clamp installation test for practicing installation techniques, the process was loosely controlled and the techniques unrefined. The

overall observation was that better prepared pipe surfaces and strictly controlled installation techniques, yielded higher ATS values. These results indicate that a better controlled and more refined installation protocol is needed to maximize the bonding strength of this adhesive clamp system.

However, clamp E had the lowest average ATS among all the diver-installed clamps. By ATI account, clamp E had been properly installed and the pipe surface sufficiently cleaned for the installation. The low ATS values may be attributed to the interference of the embedded sensors and wiring with the adhesion process. In addition, since clamp E is located in the highest bending-stress location, the post installation load-tests could have weakened the adhesive bonding. Unfortunately, the test's small sample size does not provide enough data or information to support or reject any of these possible causes. Nevertheless, this finding suggests that proper integration of the sensors and wirings into the clamp assembly could affect the bonding strength of the adhesive clamp system. This also underscores the need to better understand the effect of the post installation stresses on the bonding strength of the adhesive clamp system.

Examination of the adhesive failure modes suggests that specimens with mixed mode adhesive failure tend to have higher adhesive bonding strength. On the other hand, specimens with adhesive failure on the polyurethane surface tend to have lower adhesive bonding strength.

Table 11. Button Tensile Test Result Summary for Pipe P1

	Clamp A	Clamp B	Clamp AA*	Clamp E	Clamp BB*	Clamp C	Clamp D	Total
Number of Test Conducted	23	37	25	7	35	31	30	188
Number of Valid Tests	20	24	13	4	18	18	15	112
Number of Tab Break (Invalid) Tests	2	11	11	1	17	12	13	67
Number of Other Invalid Tests	1	2	1	2	0	1	2	9
Min. Adhesive Strength (psi)	45.0	29.8	31.1	49.5	113.6	45.8	57.5	
Max. Adhesive Strength (psi)	155.8	503.3	193.5	150.8	498.6	267.9	358.7	
Average Adhesive Strength (psi)	94.0	174.1	81.4	91.1	292.0	142.5	136.3	
Adhesive Strength Standard Deviation (psi)	30.4	112.4	47.2	46.9	108.9	65.6	73.6	
Predominate Adhesive Failure Mode	PU Surface	Steel Surface	Steel Surface	PU Surface	Mixed Mode	Mixed Mode	Steel Surface	

* - Clamps AA and BB are control samples. Clamp AA was installed underwater and Clamp BB was installed dry.

Table 12. Button Tensile Test Result Summary for Pipes P2 and P3

	Clamp F	Clamp G	Total
Number of Test Conducted	22	29	51
Number of Valid Tests	15	15	30
Number of Tab Break (Invalid) Tests	2	5	7
Number of Other Invalid Tests	5	9	14
Min. Adhesive Strength (psi)	33.6	29.7	
Max. Adhesive Strength (psi)	225.7	268.8	
Average Adhesive Strength (psi)	114.0	105.3	
Adhesive Strength Standard Deviation (psi)	53.7	59.8	
Predominate Adhesive Failure Mode	Mixed Mode	PU Surface	

In addition to the button tensile test results, additional lessons were learned regarding the execution of button tensile testing. Due to the non-standard nature of the test and the unique configuration of the test articles, it was a challenge to create a test protocol that would consistently produce valid test results. As indicated in the results summary tables 11 and 12, around 40 % of the tests conducted in this study did not yield valid test data. The challenges were related to the specimen preparation techniques. The techniques were refined continuously throughout the study. The following is a list of button specimen preparation practices that were learned and adapted in this study to yield valid test data.

- Apply proper lubrication, and clearing of debris, during the cutting of the button specimen to minimize heating and shear stress on the specimen that could weaken the adhesive bonding.
- Maintain proper alignment and stabilization of the drilling tool to ensure complete cutting of the specimen and minimize shear stress on the specimen during cutting.
- Bead blast the aluminum tab surface to increase tab-to-button bonding strength in order to minimize tab bonding failure.
- Longer tab bonding cure time of at least 72 hours increases tab-to-button bonding strength so as to minimize tab bonding failure.
- Maintain vertical alignment during curing of the tab bonding to increase tab-to-button bonding strength so as to minimize tab bonding failure.

8.0 Recommendations for Future Work

The findings from this study confirmed our past experience that proper preparation and installation techniques are critical in achieving high adhesive clamp bonding to a steel pipe in an underwater environment. Without a standardized installation protocol, the typical bonding strength of the adhesive clamp system would be difficult to establish. The following is a list of proposed future work with the objective of formulating a standard adhesive clamp installation protocol and characterizing the adhesive clamp bonding strength achieved by such protocol.

- Conduct a design study to refine the adhesive clamp design for better integration of the sensors and wirings into the adhesive clamp so as to promote the formation of a uniform adhesive thickness for maximizing bonding strength.
- Conduct a statistically designed laboratory study to investigate different adhesive clamp installation parameters, such as steel pipe surface finish, polyurethane clamp surface finish, surface cleaning procedures, and adhesive thickness, which would maximize bonding strength in underwater applications.
- Develop a standard adhesive clamp installation protocol using the optimal installation parameters determined from the laboratory study.
- Produce full scale clamp/pipe test articles using the developed protocol, and conduct button testing to verify that the installation protocol consistently produces a robust adhesive clamp-to-pipe bond.

APPENDIX A. TECHANICAL DATASHEETS

A.1 Poly 81 Series Polyurethane Technical Datasheet

Polytek Development Corp.

TECHNICAL BULLETIN

Poly 81-Series RTV Liquid Rubbers

Tough, Durable, Polyurethane Rubbers

DESCRIPTION: Use Poly 81-Series rubbers to make firm molds, mold facings, stamping tools, industrial parts, rollers, gaskets, mold shells, bumpers or pads. Poly 81-Series rubbers consist of liquid Part A and Part B, which, after mixing, cure at room temperature to tough, durable rubbers. They offer low sensitivity to moisture, and low viscosity for easy mixing and pouring.

MODEL PREPARATION: Porous models, such as wood or plaster, must be sealed with wax, soap (for plaster only), petroleum jelly, paint, PVA or shellac. Sealed or non-porous models must be coated with Pol-Ease® 2300 Release Agent or wax and allowed to dry. If a model is sealed with shellac, it must be thoroughly coated with release agent, since Poly 81-Series rubbers bond tenaciously to shellac. PolyCoat can be used as both sealer and semi-permanent release agent. A single application of PolyCoat may eliminate the need for additional release agent application prior to subsequent pours of polyurethane liquid rubber. If there is any question about the compatibility between the rubber and the prepared model surface, perform a test cure on an identical surface to determine that complete curing and good release is obtained.

Porous models must be vented from beneath to prevent trapped air from forming bubbles in the rubber.

MIXING AND CURING: Parts A and B are clear liquids. The color of Part B may vary, but it has no effect on cured rubber properties. Weigh Part B into a clean metal or plastic mixing container. Then weigh the proper amount of Part A into the same container. Mix thoroughly. Hand mixing with a Poly Paddle is best to avoid mixing air into the rubber. While mixing, scrape the sides and bottom several times to ensure thorough mixing. Vacuum degassing helps to provide bubble-free molds, but is usually not necessary. Pour the rubber as soon as it is thoroughly mixed to obtain best flow and air bubble release.

PHYSICAL PROPERTIES

	81-90	81-D45
Mix Ratio, By Weight	100A:40B	100A:20B
Hardness (Shore A/D)	A90	D45
Pour Time (min)	23	19
Demold Time (hr)	16	16
Color	Yellow	Varies
Mixed Viscosity (cP)	2,000	1,600
Specific Volume (in³/lb)	26.6	26.4

FEATURES

- Firm rubbers with Shore A90 or D45
- Easy-to-use formulations
- Reproduce finest details
- Make tough, long-lasting molds, tools & parts

Allow to cure at room temperature, 77°F (25°C). Ultimate properties are reached in about seven days, but molds may be used with care after curing for 24 to 48 hours. Heat accelerates the cure -- low temperatures slow the cure. Avoid curing in areas where the temperature is below 60°F (15°C).

Both Parts A and B react with atmospheric moisture and, therefore, should be used up as soon as possible after opening. After opening, but before resealing, spray Poly Purge™ Dry Gas into containers to displace moist air and extend storage life of the products. For 55-gallon drums of Parts A and B, affix Drierite cartridges on the small bung during dispensing to protect product from moist air entering the drum.

USING THE MOLD: Usually, no release agent is necessary when casting plaster or molten wax in Poly 81-Series molds. Sponging, dipping or spraying the mold with Pol-Ease® Mold Rinse before pouring plaster in the mold reduces air bubbles in the plaster and aids release. When casting resins, lightly spray the mold with Pol-Ease® 2300 Release Agent. When casting concrete, Pol-Ease® 2650 or 2601 Release Agents offer outstanding performance.

PACKAGING
Poly 81-Series

Product (Mix Ratio)	Unit Weight (lb)	Component Weight (lb)	
		Part A	Part B
Poly 81-90 (100A:40B)	11.2	8.0	3.2
	56.0	40.0	16.0
	280	200	80.0
	630	450	180
Poly 81-D45 (100A:20B)	9.6	8.0	1.6
	48.0	40.0	8.0
	192	160	32.0
	540	450	90.0

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Poly 81-Series molds will last many years if stored undistorted on a flat surface in a cool, dry location out of direct sunlight.

CLEAN UP: Tools should be wiped clean before the rubber cures. Denatured ethanol is a good cleaning solvent, but is highly flammable and must be handled with extreme caution. Work surfaces can be waxed or coated with Pol-Ease® 2300 Release Agent so that cured rubber can be removed.

SAFETY: Before use, read product labels and Material Safety Safety Sheets. Follow safety precautions and directions. Contact with uncured products may cause eye, skin and respiratory irritation, and dermal and/or respiratory sensitization. Avoid contact with skin and eyes. Use with adequate ventilation. Poly 81-Series rubbers are not to be used where food or body contact may occur. Poly 81-Series mold rubbers burn readily when ignited.

STORAGE LIFE: At least twelve months stored in unopened containers at room temperature (60-90°F).

DISCLAIMER: The information in this bulletin and otherwise provided by Polytek® is considered accurate. However, no warranty is expressed or implied regarding the accuracy of the data, the results to be obtained by the use thereof, or that any such use will not infringe any patent. Before using, the user shall determine the suitability of the product for the intended use and user assumes all risk and liability whatsoever in connection therewith.

ACCESSORIES

Pol-Ease® 2300 Release Agent
12-oz can, case of 12 cans

Pol-Ease® 2500 Release Agent
12-oz can, case of 12 cans

Pol-Ease® 2601 Release Agent
1 qt (2 lb), 5 gal (40 lb), Drum (450 lb)

Pol-Ease® 2650 Release Agent
1 qt (1.5 lb), 5 gal (35 lb), Drum (375 lb)

Pol-Ease® Mold Rinse
5 gal (40 lb)

Poly PVA Solution (Green or Clear)
1 qt (2 lb), 5 gal (40 lb)

Poly Purge™ Aerosol Dry Gas
10-oz can, case of 12 cans

PolyCoat
1 qt (1.5 lb), 1 gal

PolyColors
Red, Blue, Green, Yellow, Brown & Black
4 oz (0.25 lb), 1 pt (1.0 lb)

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A.2 Syntho-Subsea LV Technical Datasheet

SYNTHO-SUBSEA™ LV

LOW VISCOSITY, SELF LEVELING, UNDERWATER EPOXY MASTIC SEALANT SYSTEM

Description

Syntho-Subsea™ LV Epoxy is a unique blend of liquid epoxy, polymer, and aliphatic polyamine curing agents that is able to displace water from wet surfaces in order to make a permanent bond. The formulation is solvent-free to ensure safety and maximum technical performance. Kevlar® fibers are incorporated for reinforcement and viscosity management to achieve high-application rates – even subsea. Provides permanent protection under the most adverse conditions, the formula is uniquely field-friendly and uses advanced, low-toxicity ingredients in a high-build brushable/rollable product. This versatile epoxy system can achieve high-performance characteristics, excellent adhesion, resistance to high pressures, resistance to high and low temperature extremes, as well as outstanding resistance to petroleum products and chemicals. This product can also be used for aboveground and belowground applications. Syntho-Subsea™ LV Epoxy can be shipped non-regulated by USDOT, IATA, and IMO.

Mechanical Properties

Test	Method	Result
Tensile Strength	ASTM D3039	6,000 psi (413.68 bar)
Compression Strength	ASTM D695	7,380 psi (508.83 bar)
Flexural Strength	ASTM D790	4,550 psi (313.71 bar)
Flexural Modulus	ASTM D790	142,188 psi (9803.51 bar)
Lap Shear Strength	ASTM D3163	1,782 psi (122.86 bar)
Abrasion Resistance	CS17 wheels with 1,000 gram weights	34.0 mg/1,000 cycles

Item #	Description
SUBLV_04OZ	4 oz (197g) Bi-Pack
SUBLV_08OZ	8 oz (394g) Bi-Pack
SUBLV_16OZ	16 oz (787g) Bi-Pack
SUBLV2QT	2qt (1.892l) Kit contains 1qt A+1qt B
SUBLV2G	2 gal (7.570l) Kit contains 1gal A+1gal B
SUBLV10G	10 gal (37.854l) Kit contains 5gal A+5gal B

Typical Applications

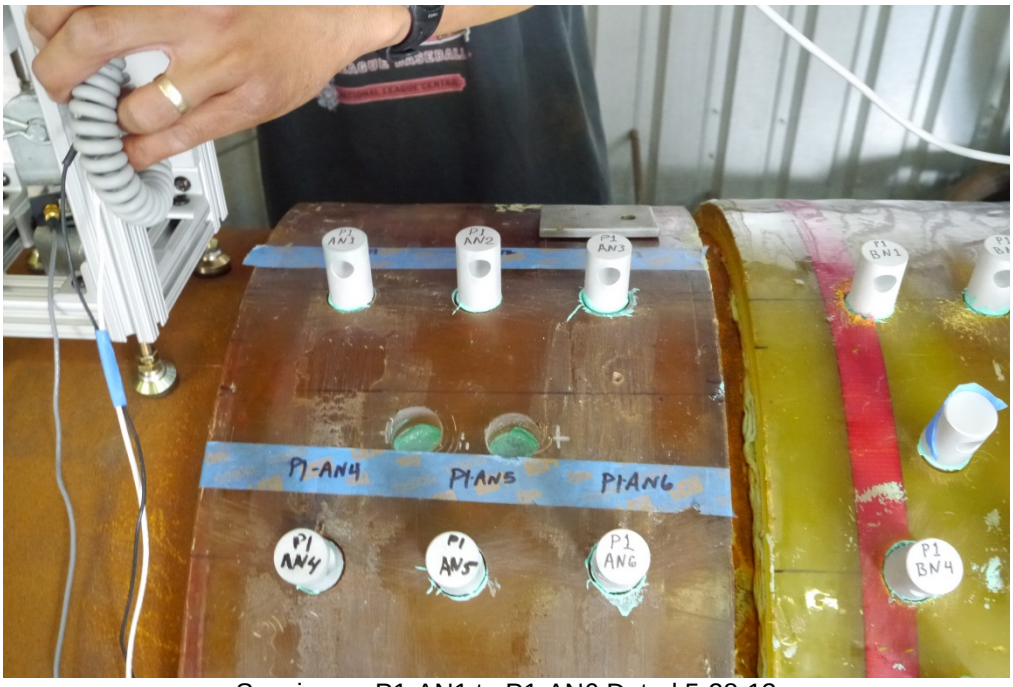
- Anticorrosive coating
  - Splash zone/ Subsea applications
- Encapsulating coating
- Chemical resistant coating
- Excellent abrasive resistance
- Pipeline repairs
- Concrete repairs
- Pipeline anomaly reinforcement and remediation

Physical Properties

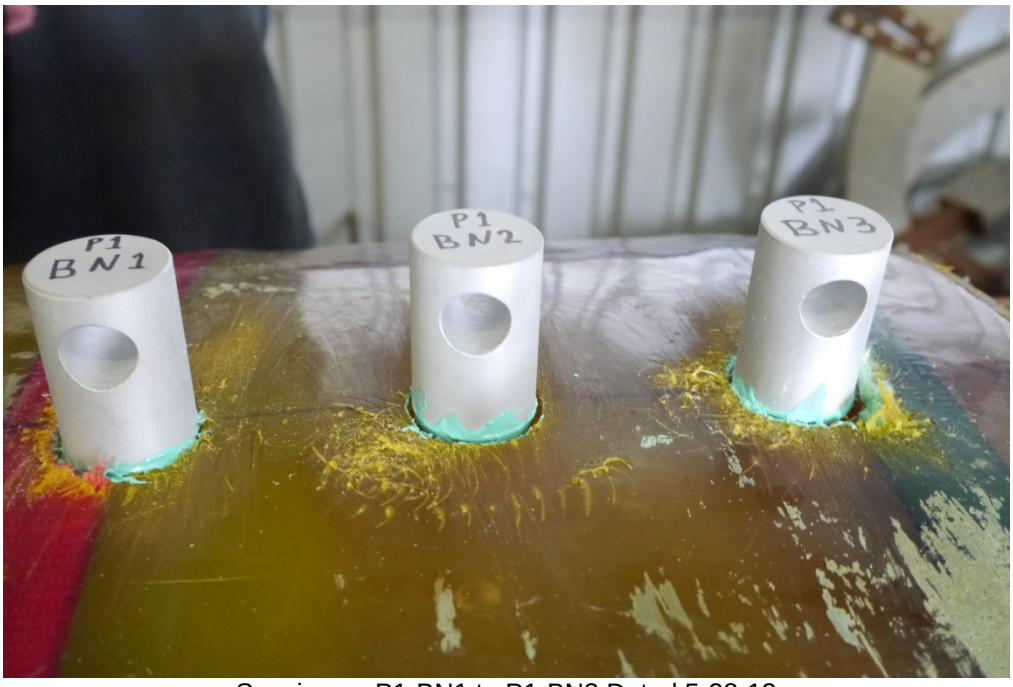
VOCs: None
Color: Resin - White, Curing Agent - Green
Pot Life: 20 Minutes at 77°F (25°C)
Cure Time: 24 Hours at 77°F (25°C)
Service Temperature:
Dry: -50° to 275°F (-45° to 135°C)
Wet: -50° to 160°F (-45° to 71°C)
Mixing Ratio: 1:1 by volume
Flash Point: Over 200°F (93°C)
Solids Content: 100%
Spreading Rate/Gallon:
1,604 mil/sq. ft.
53.5 sq. ft./30 mils
Shelf Life: 24 Months with recommended storage conditions

APPENDIX B. BEFORE-TEST PHOTOGRAPHS

Specimens P1-AE1 to P1-AE5 Dated 5-28-13



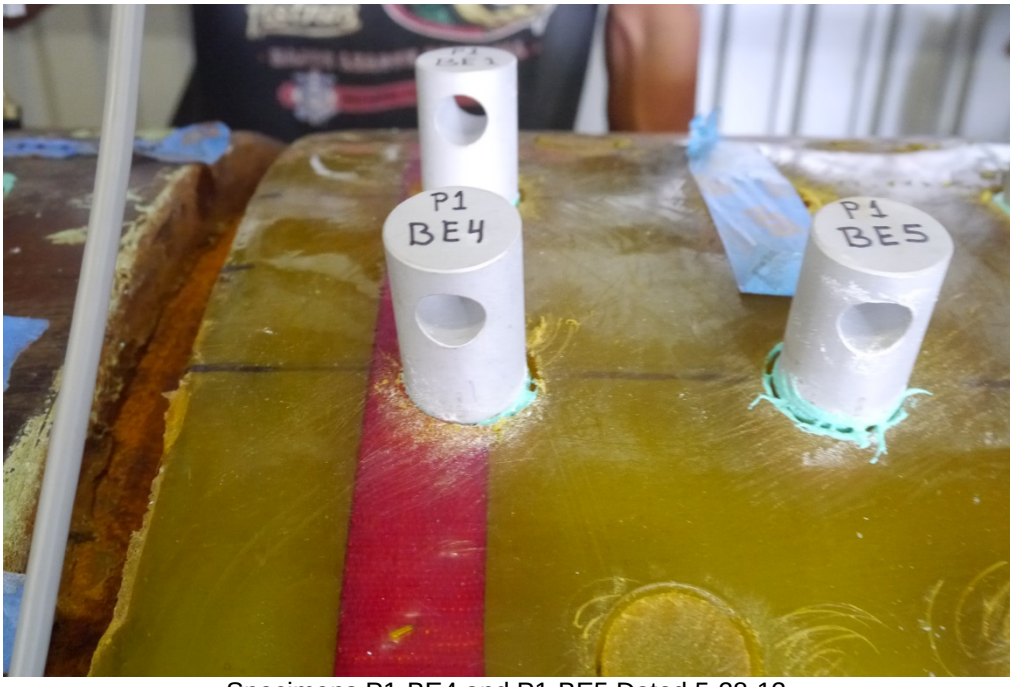
Specimens P1-AN1 to P1-AN6 Dated 5-28-13



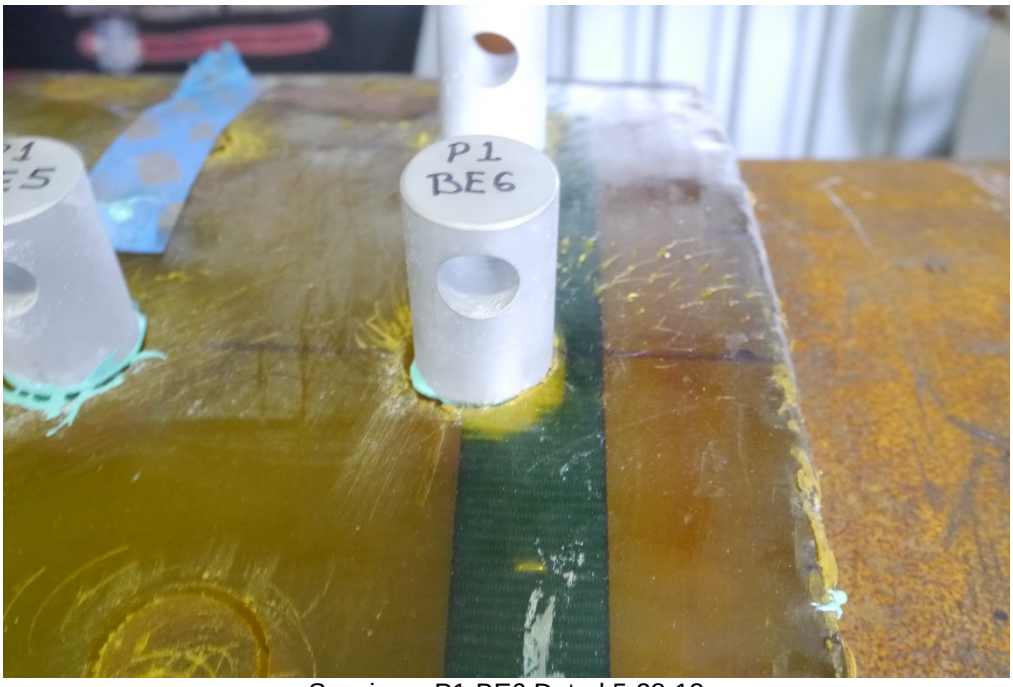
Specimens P1-BN1 to P1-BN3 Dated 5-28-13

Specimen P1-BE1 Dated 5-28-13

Specimen P1-BE3 Dated 5-28-13



Specimens P1-BE4 and P1-BE5 Dated 5-28-13



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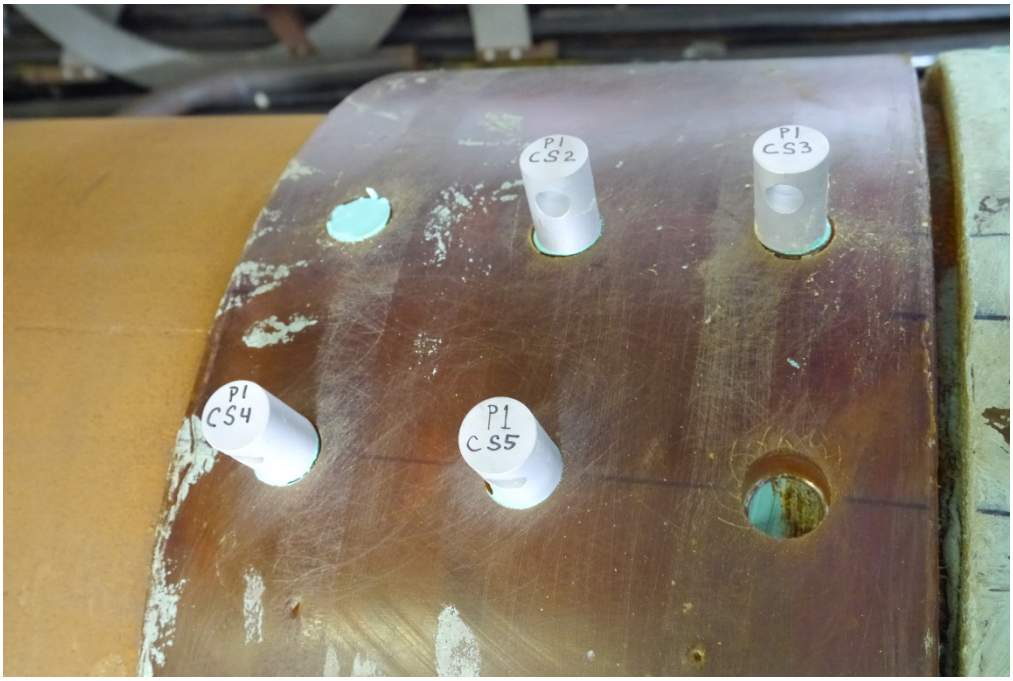
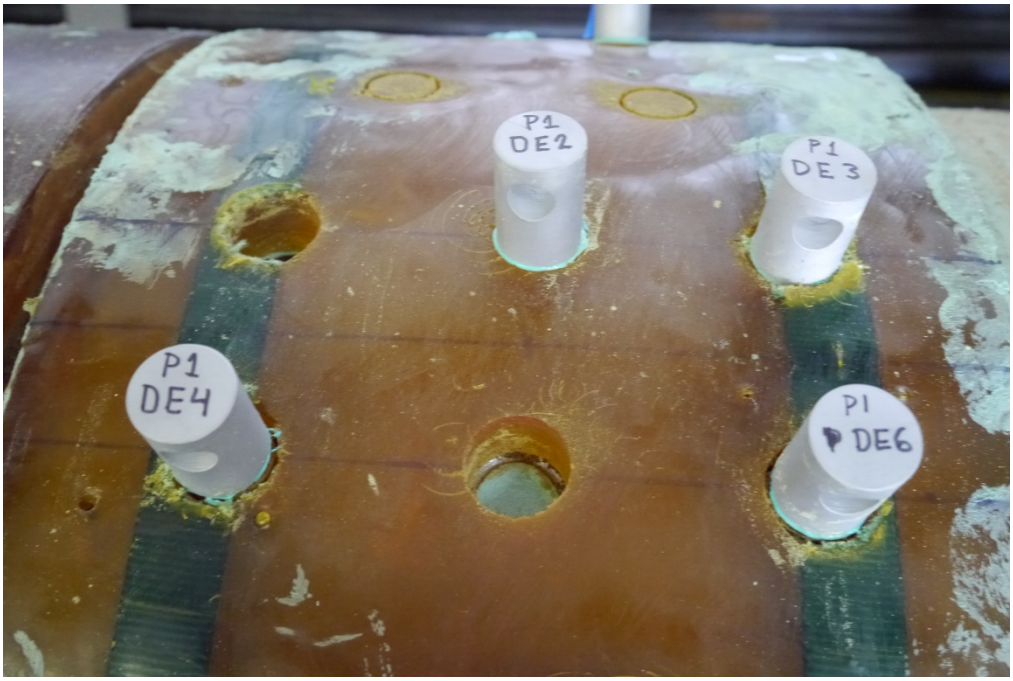


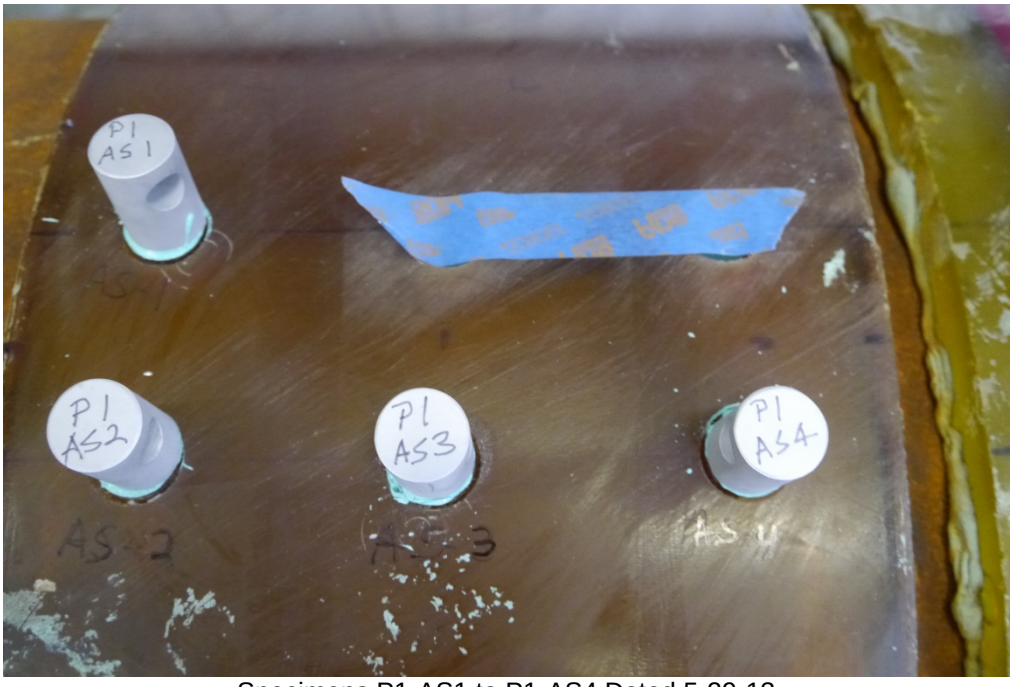
Specimens P1-CS2 to P1-CS5 Dated 5-28-13

Specimens P1-CE1 to P1-CE6 Dated 5-28-13



Specimens P1-DE2, P1-DE3, P1-DE4, and P1-DE6 Dated 5-28-13

Specimens P1-DS3, P1-DS5, and P1-DS-6 Dated 5-28-13



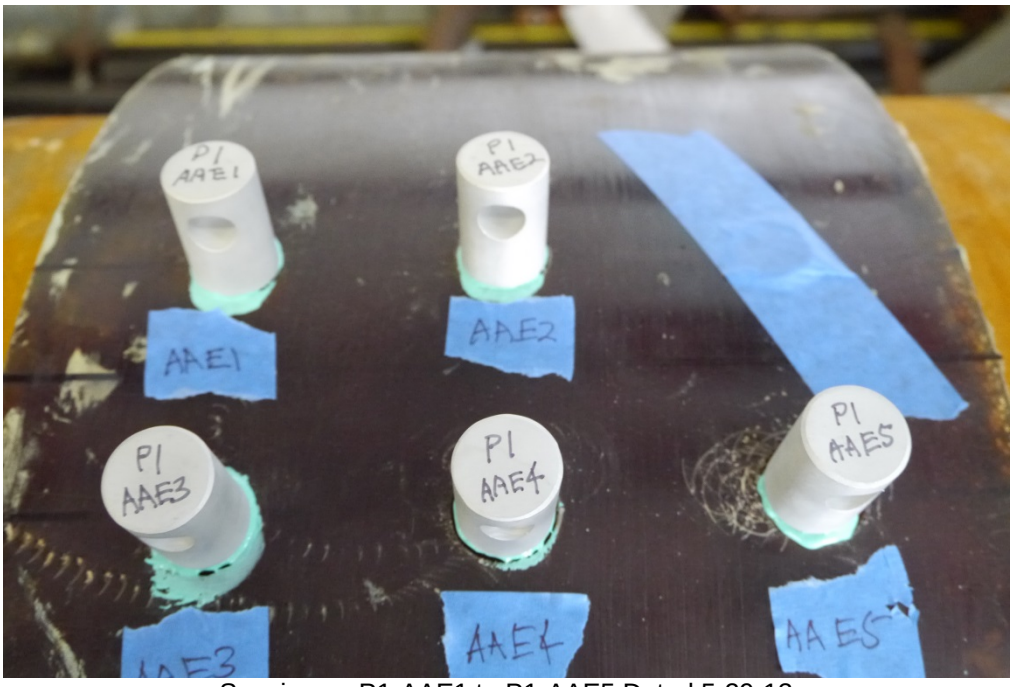
Specimens P1-AS1 to P1-AS4 Dated 5-29-13

Specimens P1-BS1 to P1-BS7 Dated 5-29-13

Specimens P1-AAS1 to P1-AAS5 Dated 5-29-13

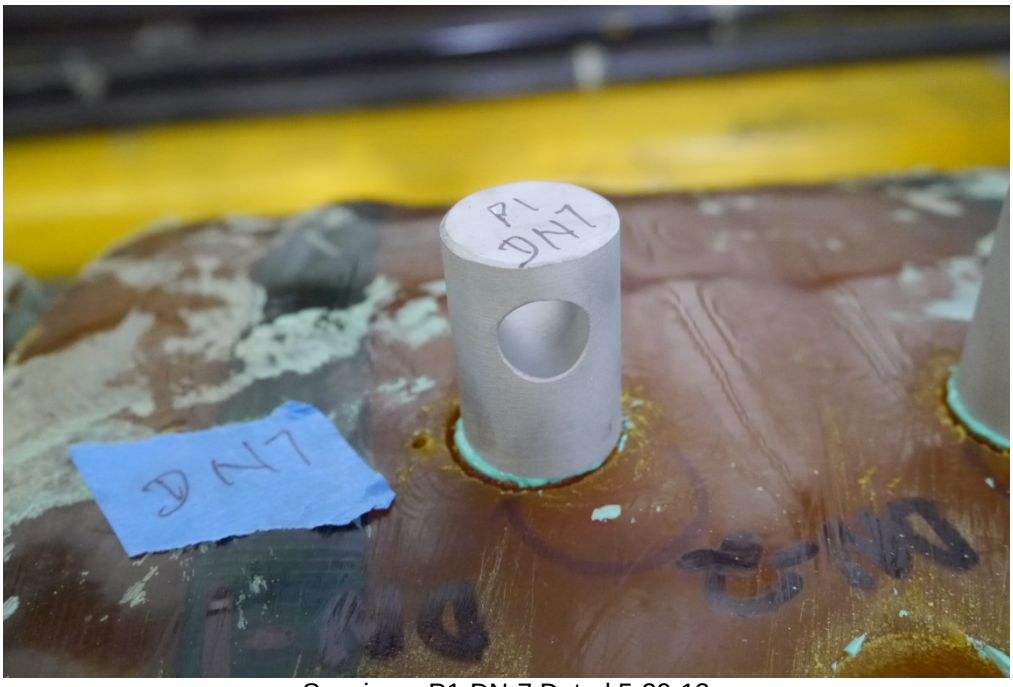
Specimens P1-BBS1 to P1-BBS6 Dated 5-29-13

Specimens P1-DS1, P1-DS2, P1-DS4, and P1-DS7 Dated 5-29-13



Specimens P1-AAE1 to P1-AAE5 Dated 5-29-13

Specimens P1-BBE-1 to P1-BBE6 Dated 5-29-13



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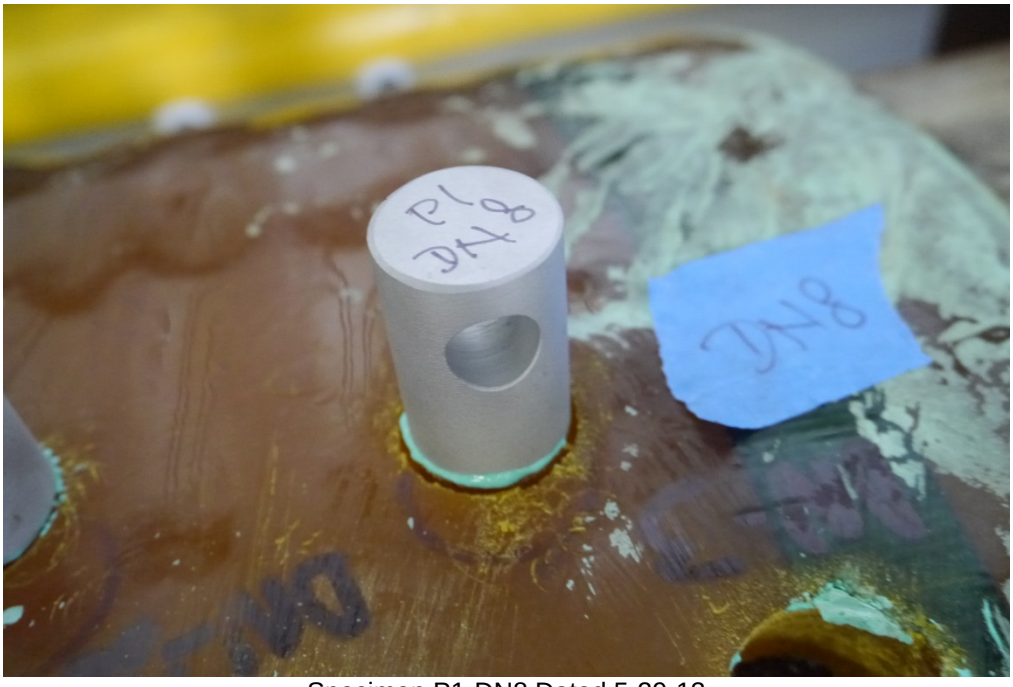

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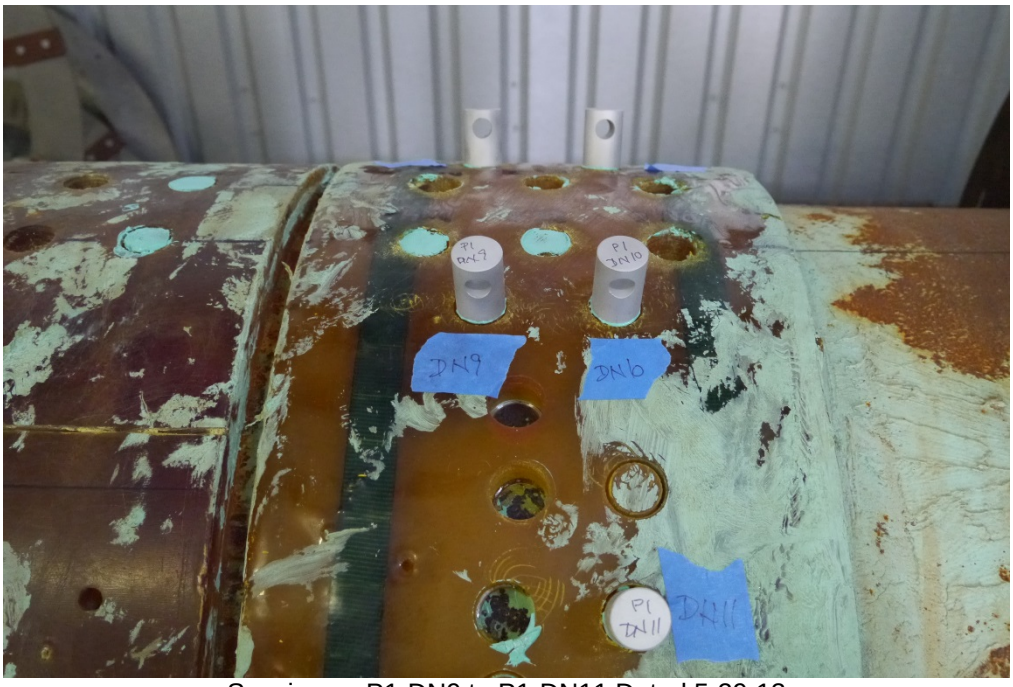
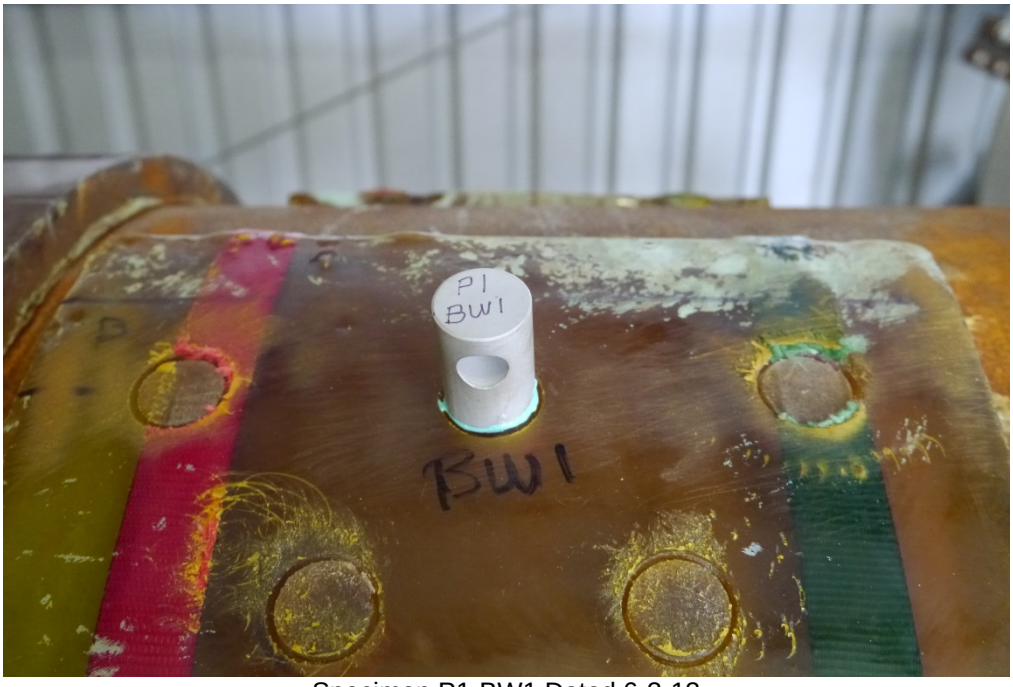


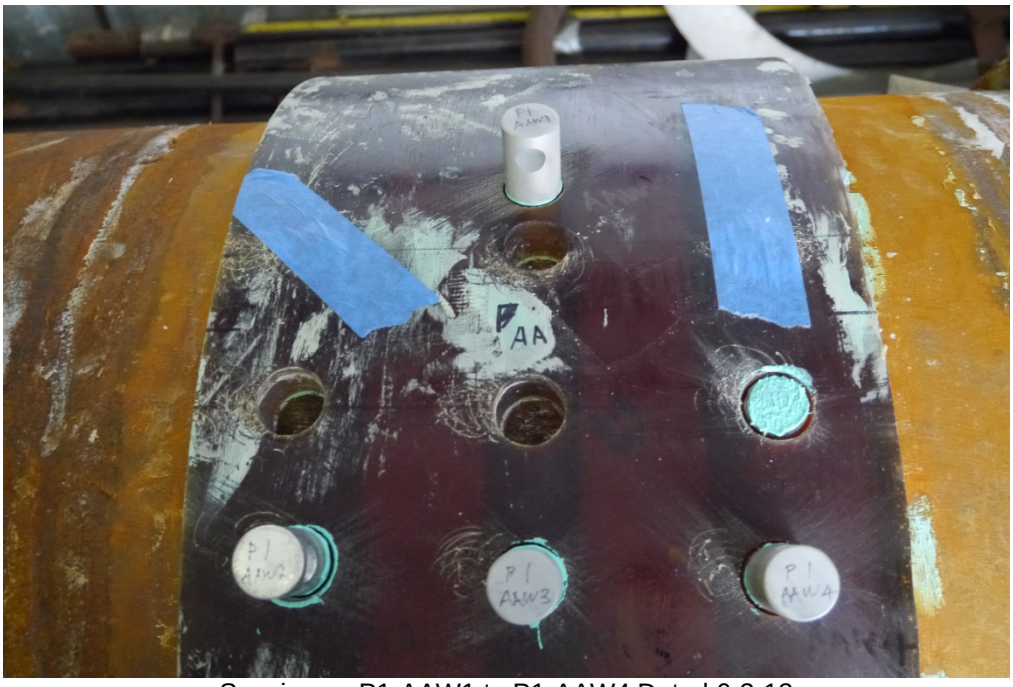
Specimens P1-DN9 to P1-DN11 Dated 5-29-13

Specimens P1-CW1 to P1-CW5 Dated 5-29-13

Specimens P1-DW1 to P1-DW3 Dated 5-29-13



Specimen P1-BW1 Dated 6-3-13

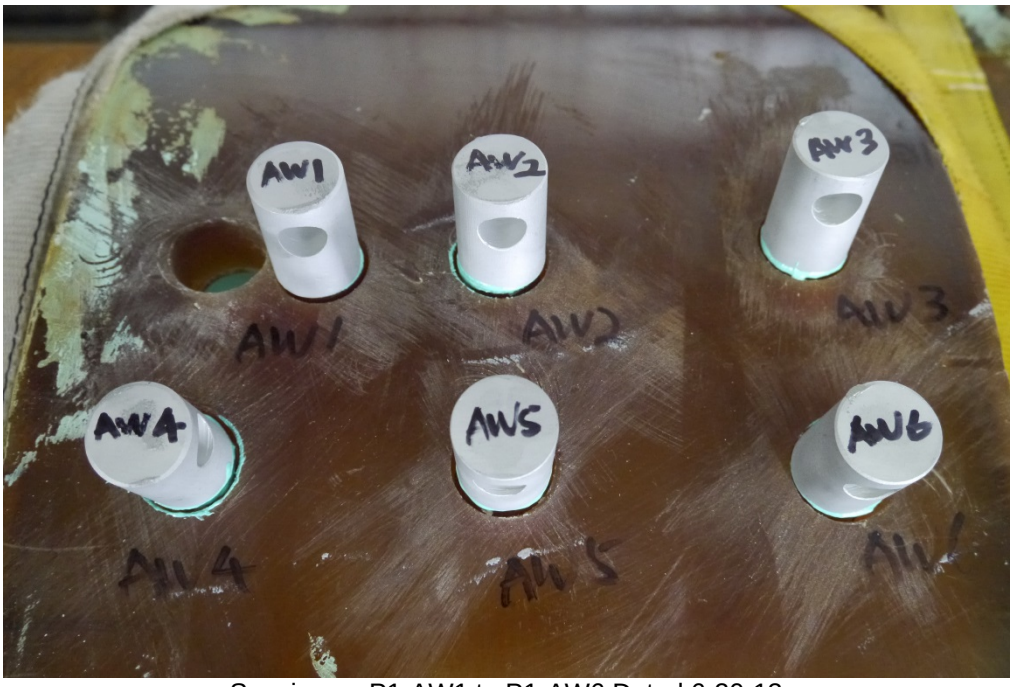


Specimens P1-AAW1 to P1-AAW4 Dated 6-3-13

Specimens P1-AAN4 to P1-AAN6 Dated 6-3-13

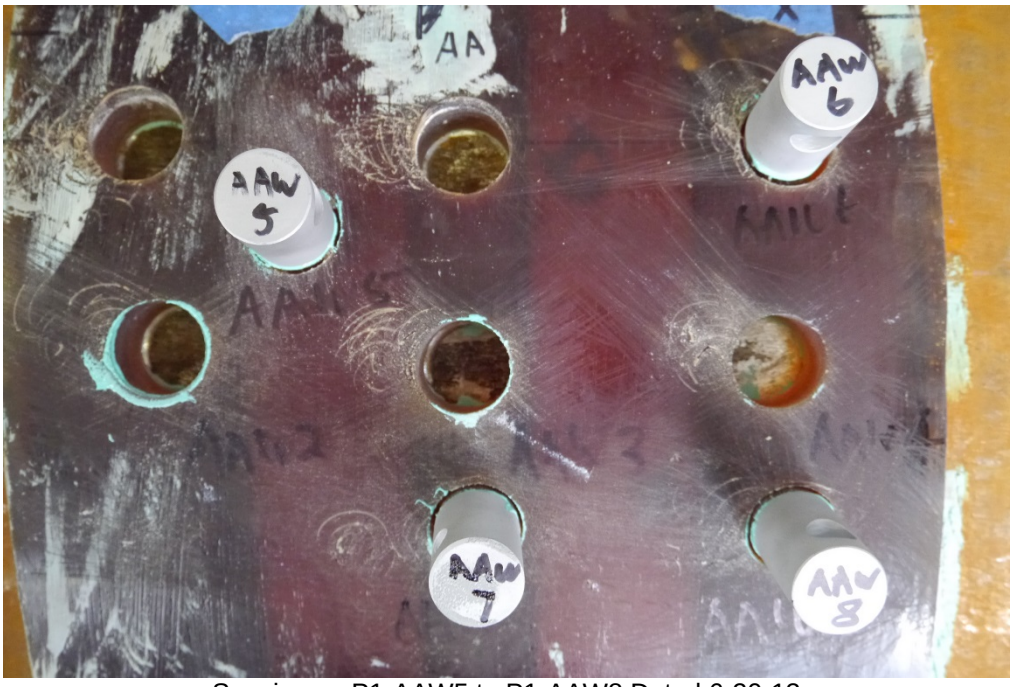
Specimens P1-AAE6 to P1-AAE8 Dated 6-3-13

Specimens P1-BBW1 to P1-BBW3 Dated 6-3-13



Specimens P1-AW1 to P1-AW6 Dated 6-20-13

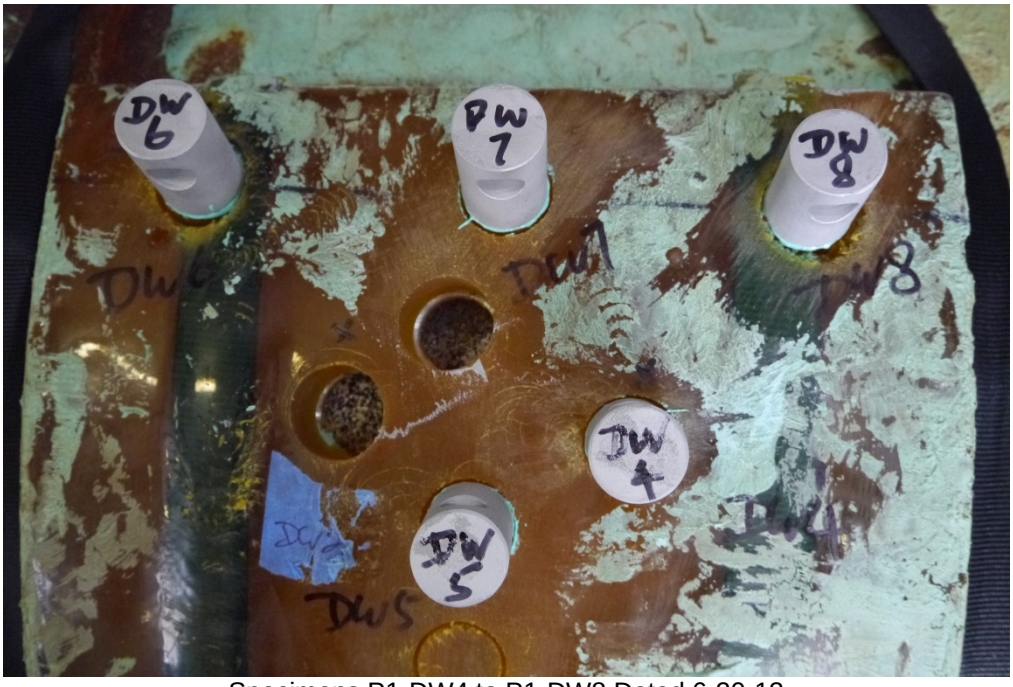
Specimens P1-BW2 to P1-BW8 Dated 6-20-13



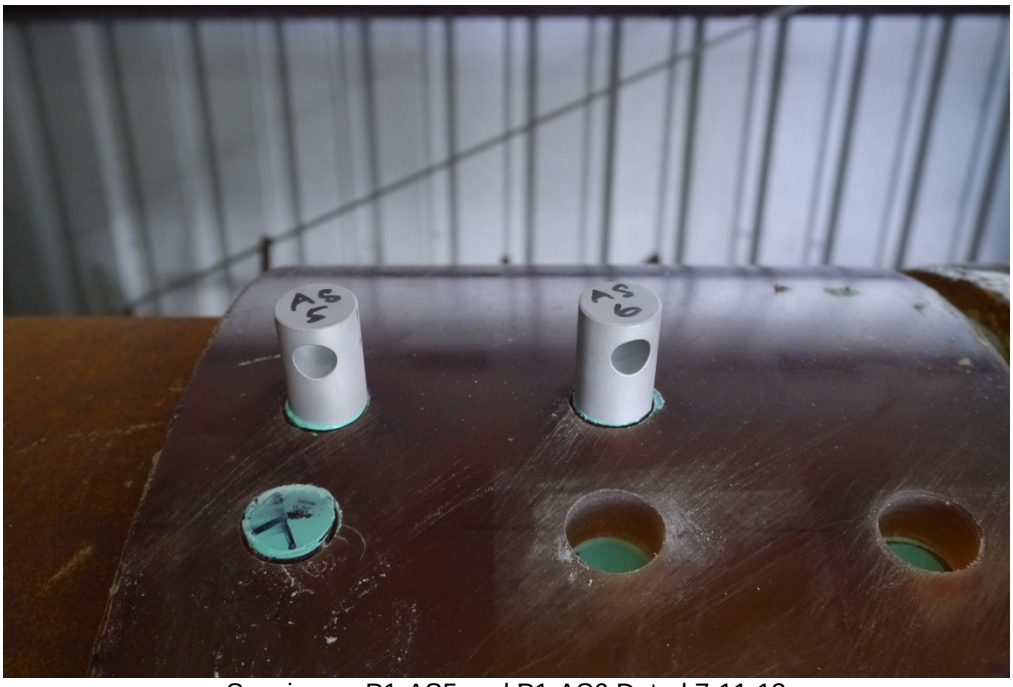
Specimens P1-AAW5 to P1-AAW8 Dated 6-20-13

Specimens P1-BBW4 to P1-BBW6 Dated 6-20-13

Specimens P1-CW6 to P1-CW11 Dated 6-20-13



Specimens P1-DW4 to P1-DW8 Dated 6-20-13



Specimens P1-AS5 and P1-AS6 Dated 7-11-13

Specimens P1-ES1 to P1-ES3 Dated 7-11-13

Specimens P1-BBS7 to P1-BBS9 Dated 7-11-13

Specimens P1-BE7 to P1-BE10 Dated 7-11-13

Specimens P1-EE1 to P1-EE4 Dated 7-11-13

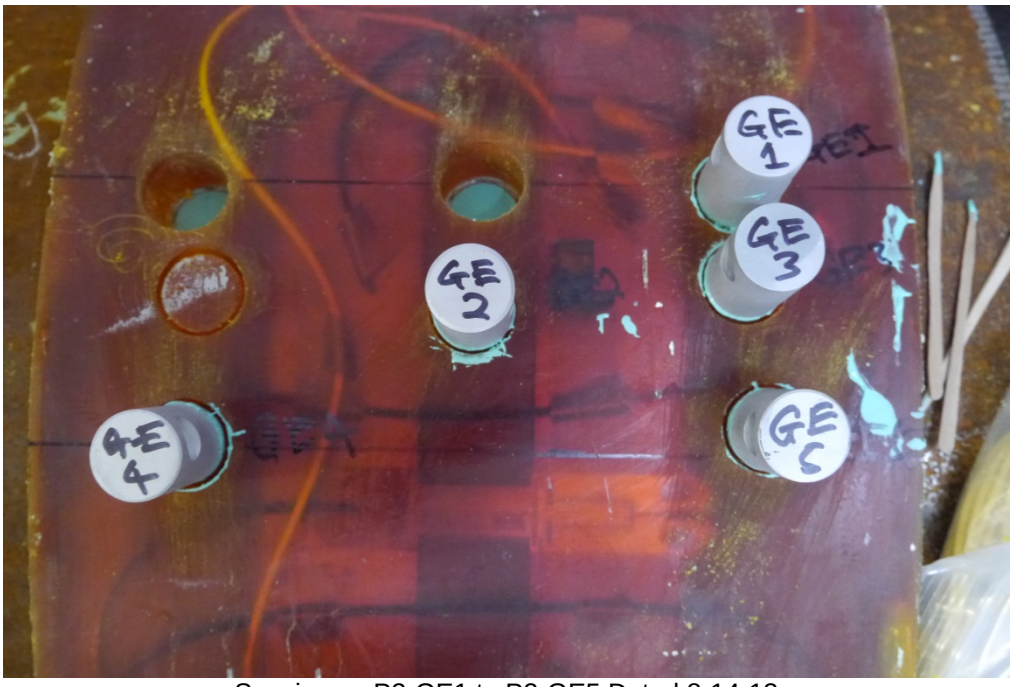
Specimens P1-BBE7 to P1-BBE10 Dated 7-11-13

Specimens P1-CE7 to P1-CE10 Dated 7-11-13

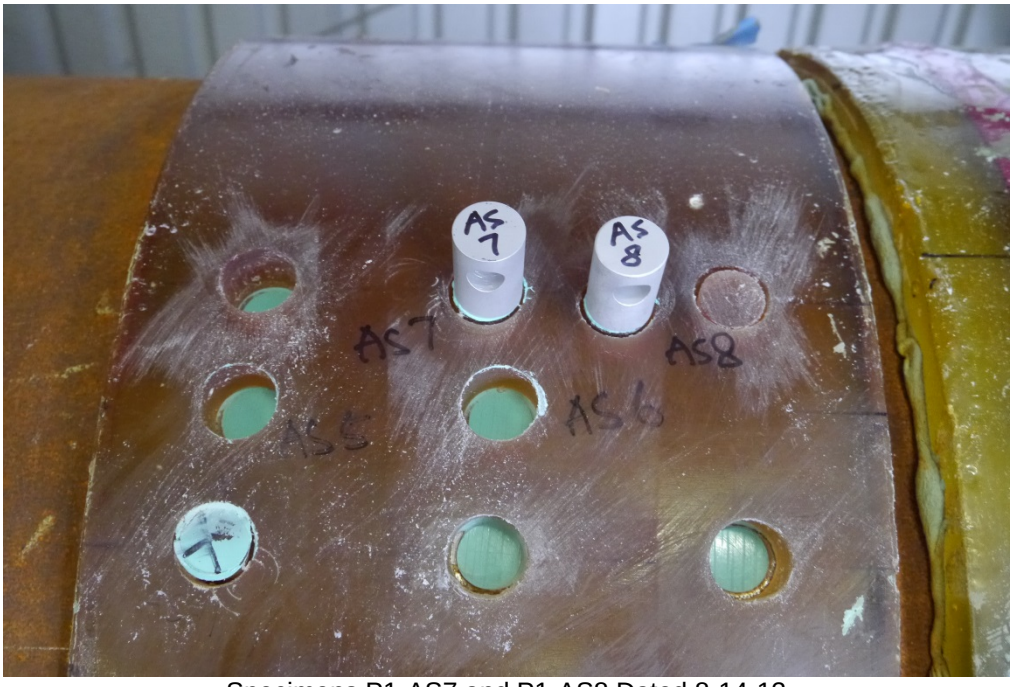
Specimens P1-BBN7 and P1-BBN8 Dated 8-14-13

Specimens P1-CN4 to P1-CN6 Dated 8-14-13

Specimens P2-FN1 to P2-FN5 Dated 8-14-13



Specimens P2-GE1 to P2-GE5 Dated 8-14-13



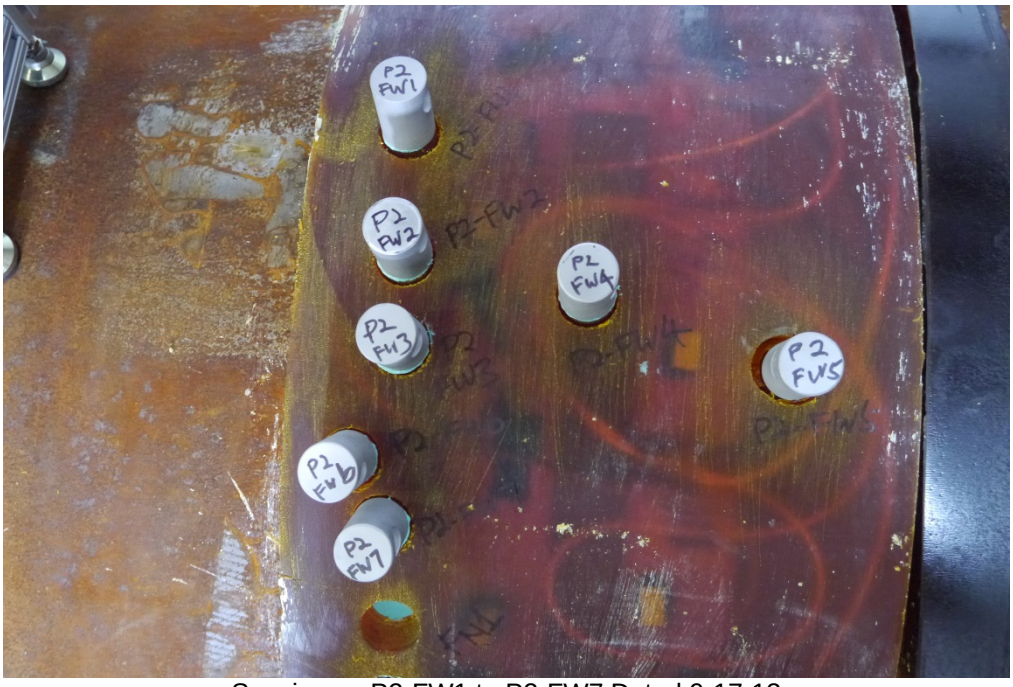
Specimens P1-AS7 and P1-AS8 Dated 8-14-13

Specimens P1-BS8 to P1-BS10 Dated 8-14-13

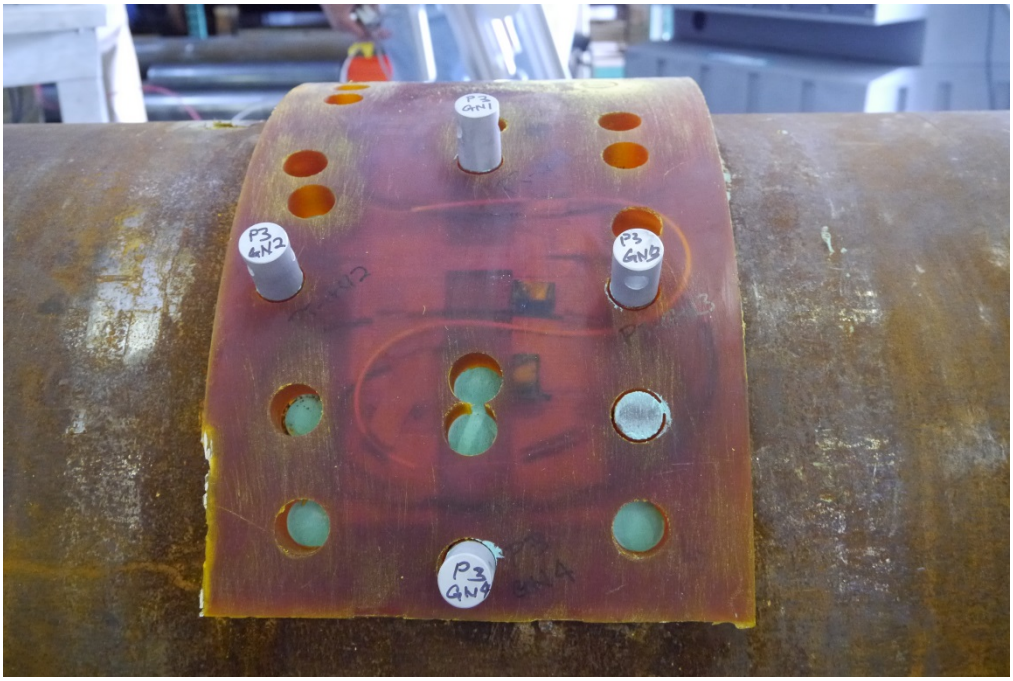
Specimens P1-BBS-13 to P1-BBS15 Dated 9-17-13

Specimens P2-FE-1 to P2-FE5 Dated 9-17-13

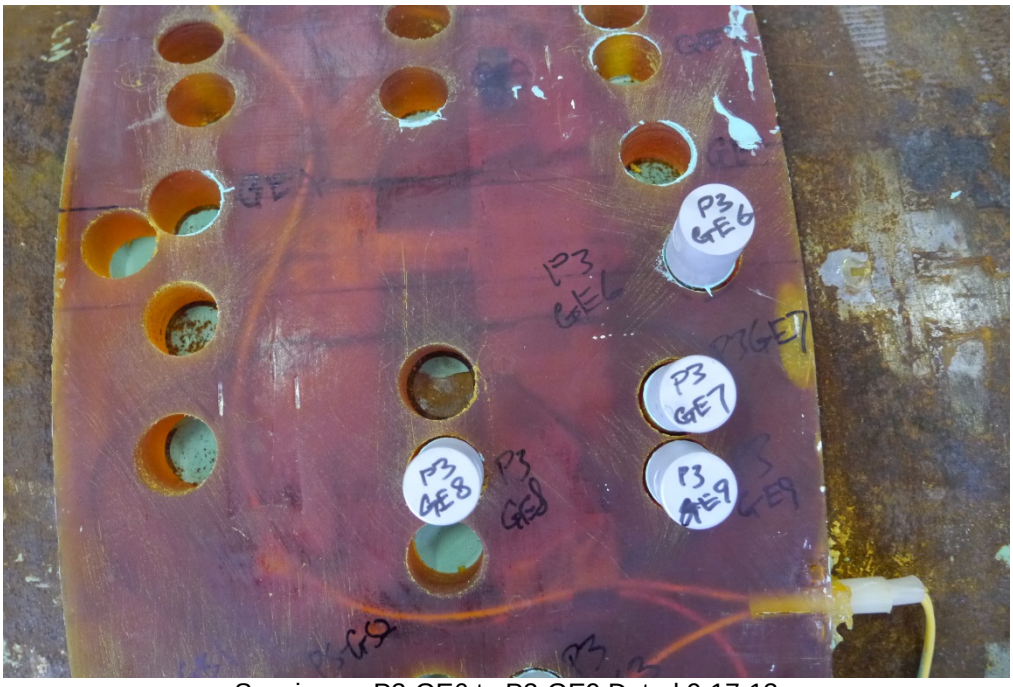
Specimens P2-FS1 to P2-FS5 Dated 9-17-13



Specimens P2-FW1 to P2-FW7 Dated 9-17-13



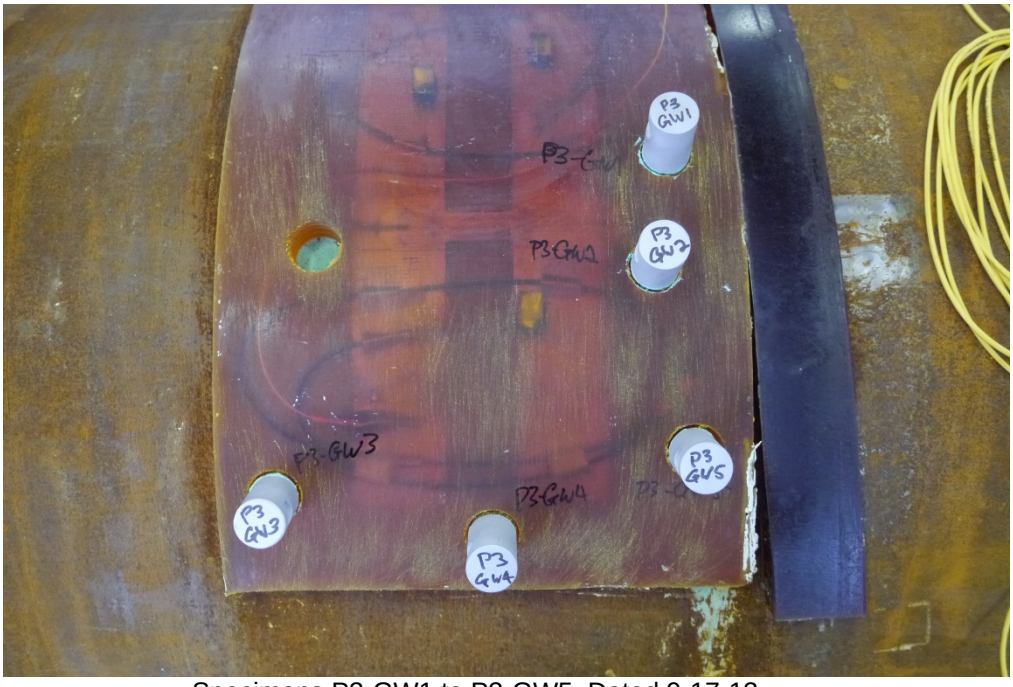
Specimens P3-GN1 to P3-GN4 Dated 9-17-13



Specimens P3-GE6 to P3-GE9 Dated 9-17-13

Specimens P3-GS1 to P3-GS6 Dated 9-17-13

Specimens P3-GS7 to P3-GS11 Dated 9-17-13



Specimens P3-GW1 to P3-GW5, Dated 9-17-13

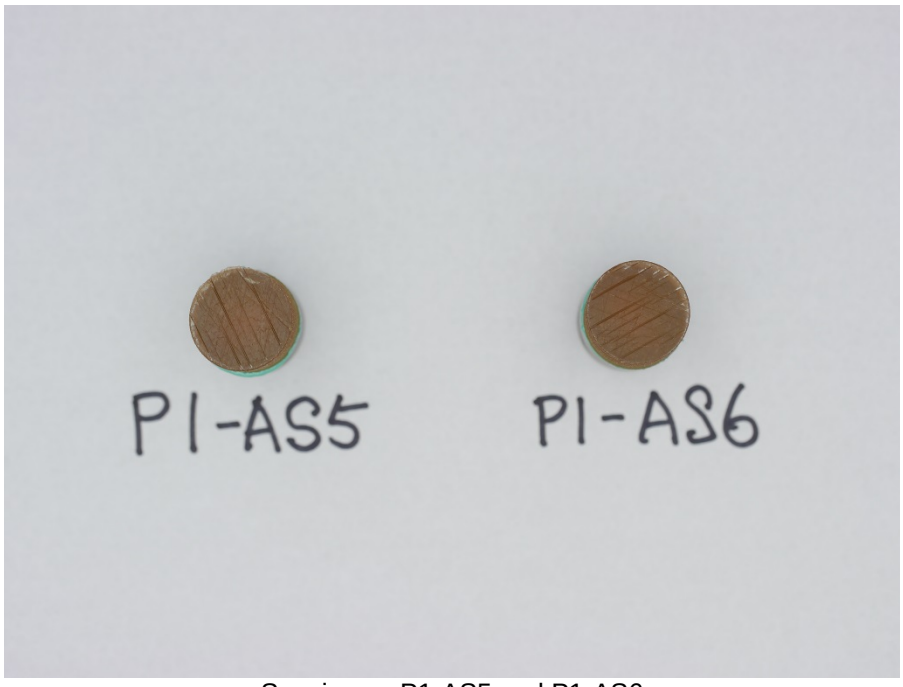
APPENDIX C. AFTER-TEST PHOTOGRAPHS

Specimens P1-AN1, P1-AN2 and P1-AN3

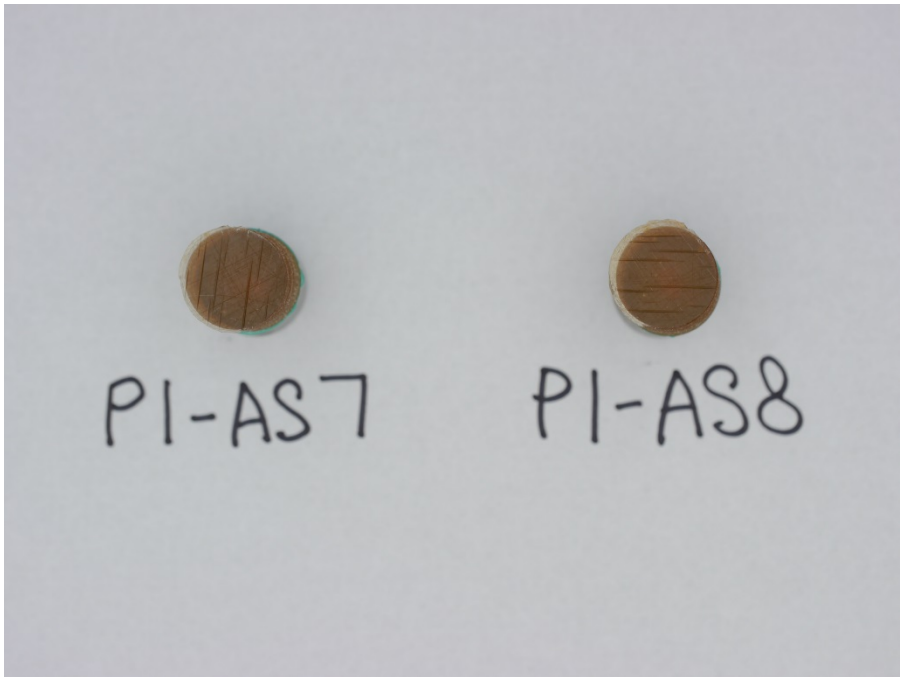
Specimens P1-AN5 and P1-AN6

Specimens P1-AE2, P1-AE3, and P1-AE4 Post Test Surfaces

Specimens P1-AS2, P1-AS3, and P1-AS4

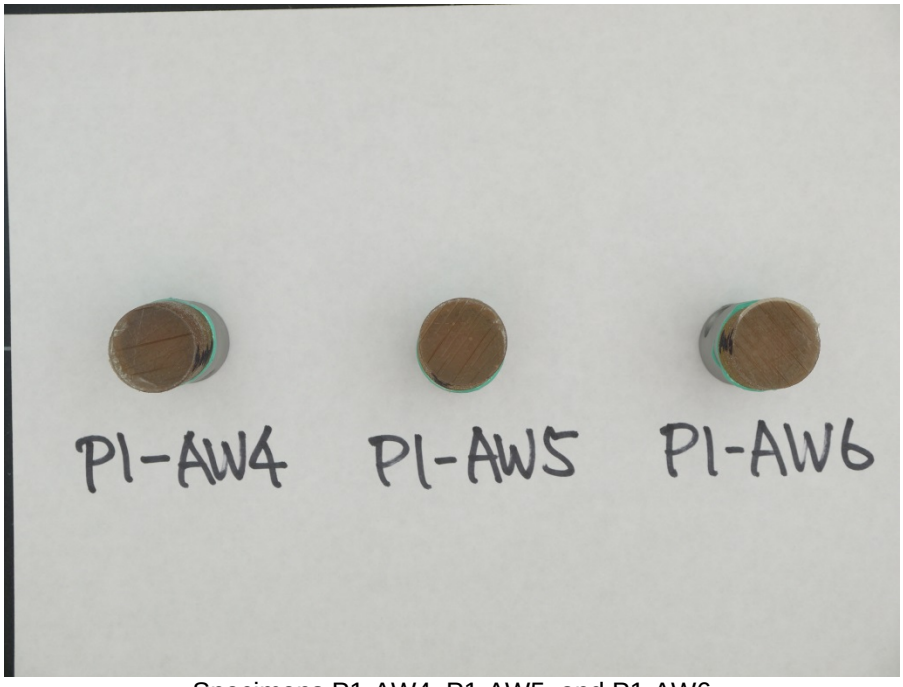


Specimens P1-AS5 and P1-AS6

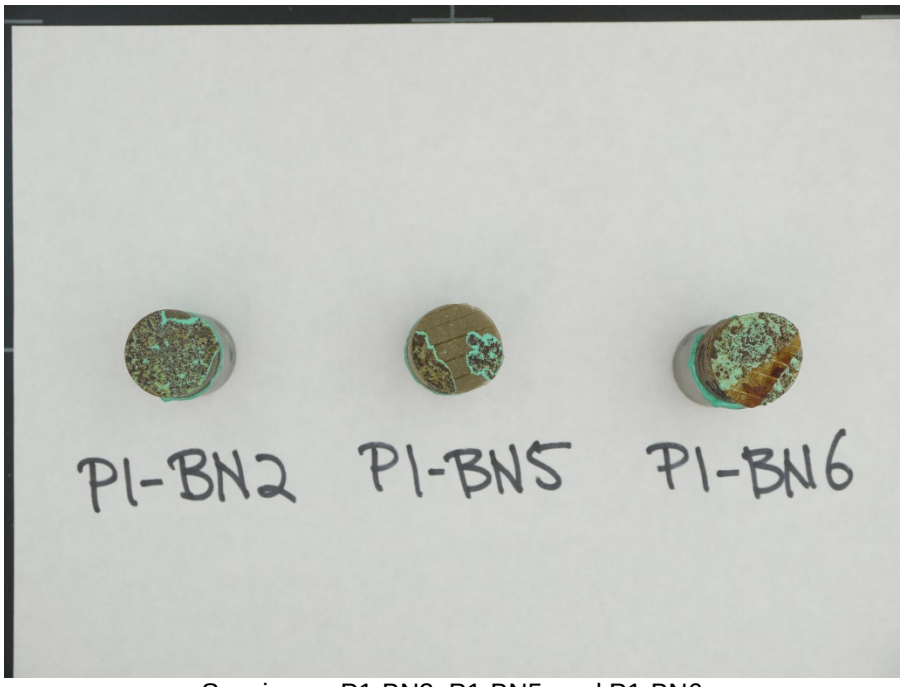


Specimens P1-AS7 and P1-AS8

Specimens P1-AW1, P1-AW2, and P1-AW3



Specimens P1-AW4, P1-AW5, and P1-AW6



Specimens P1-BN2, P1-BN5, and P1-BN6

Specimens P1-BN7, P1-BN8, and P1-BN9

Specimens P1-BE1 and P1-BE5

Specimens P1-BE7, P1-BE8, and P1-BE9

Specimens P1-BS1, P1-BS2, and P1-BS3

Specimens P1-BS4, P1-BS5, and P1-BS6

Specimen P1-BS7

Specimens P1-BS8, P1-BS9, and P1-BS10

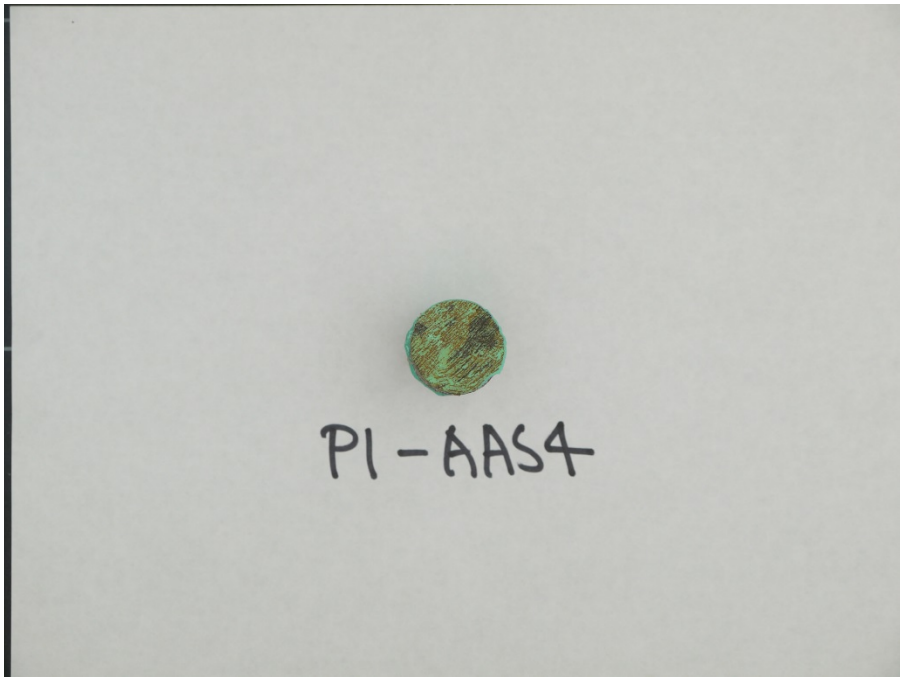
Specimens P1-BW1, P1-BW2, and P1-BW3

Specimens P1-BW4, P1-BW5, and P1-BW6

Specimens P1-BW7 and P1-BW8

Specimens P1-AAN4, P1-AAN5, and P1-AAN6

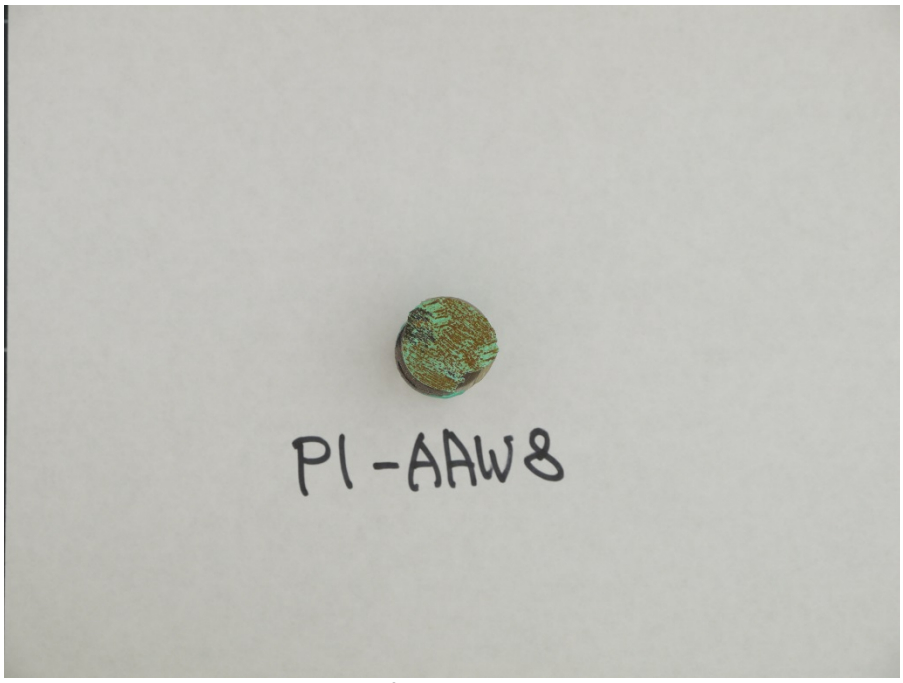
Specimens P1-AAE6, P1-AAE7, and P1-AAE8



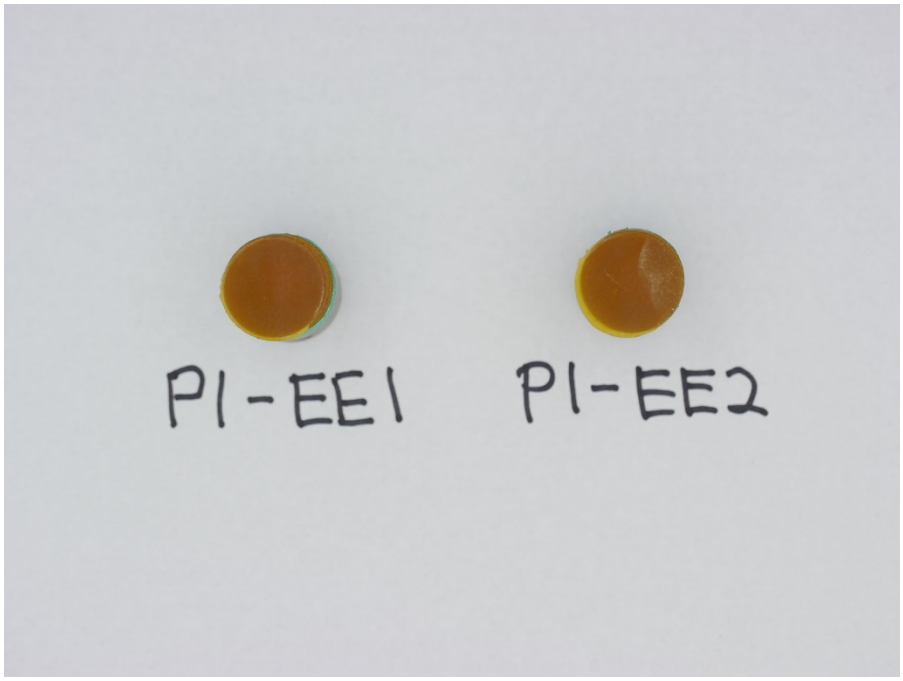
Specimen P1-AAS4

Specimens P1-AAW1, P1-AAW2, and P1-AAW3

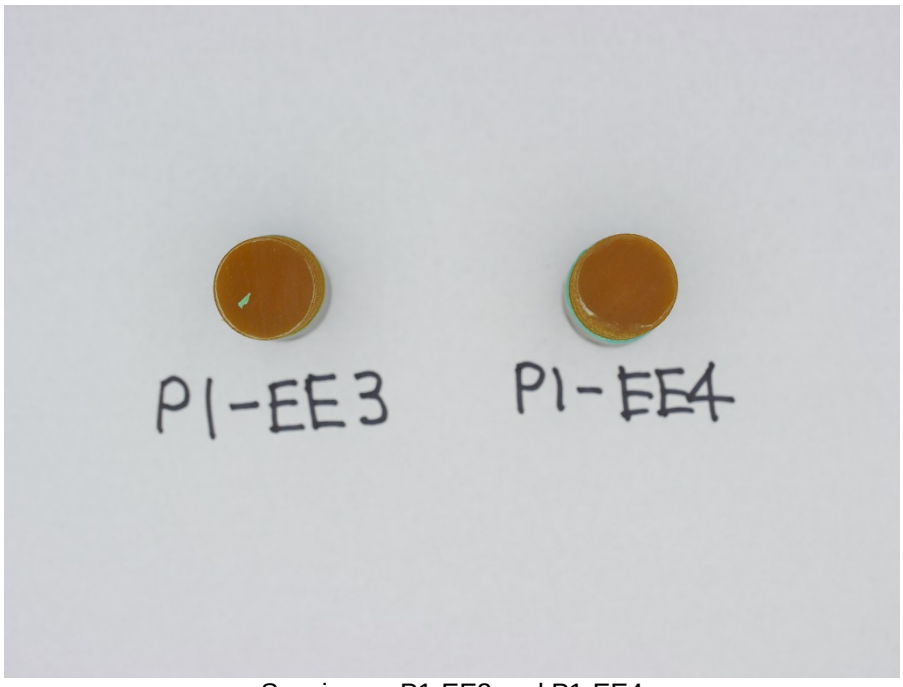
Specimens P1-AAW4, P1-AAW6, and P1-AAW7



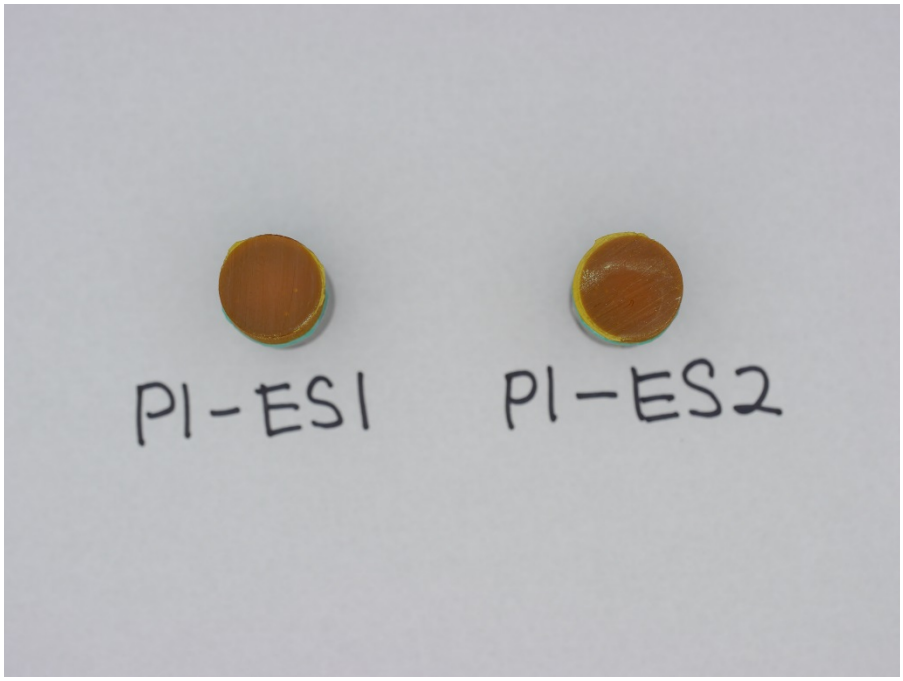
Specimen P1-AAW8



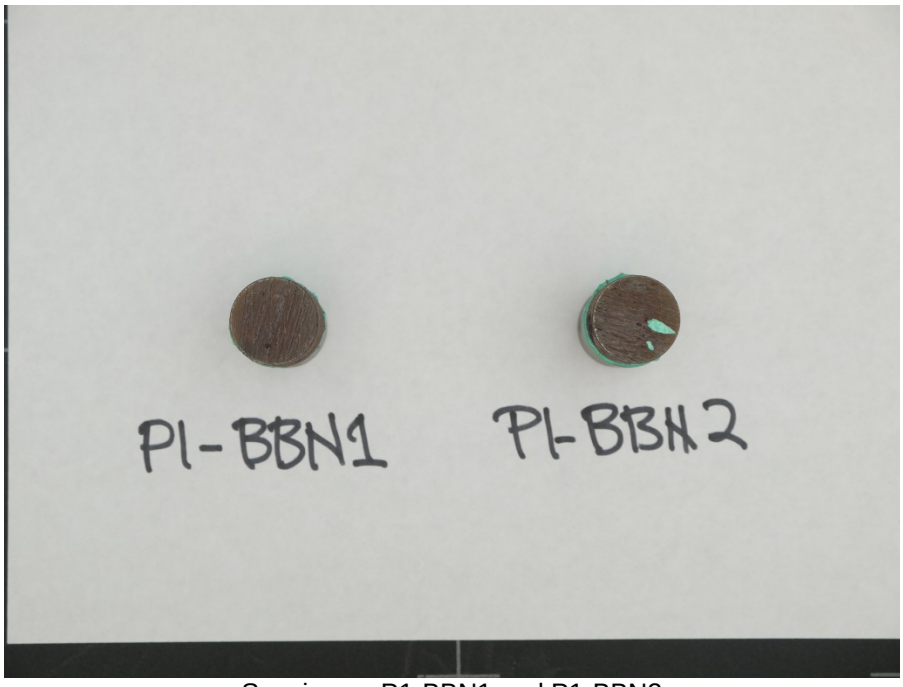
Specimens P1-EE1 and P1-EE2



Specimens P1-EE3 and P1-EE4

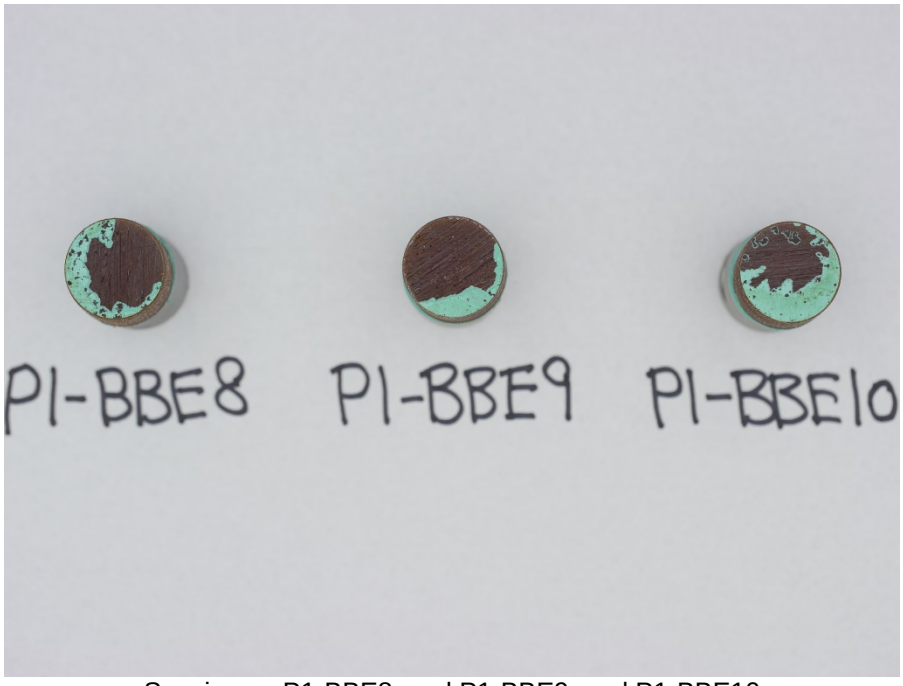


Specimens P1-ES1 and P1-ES2

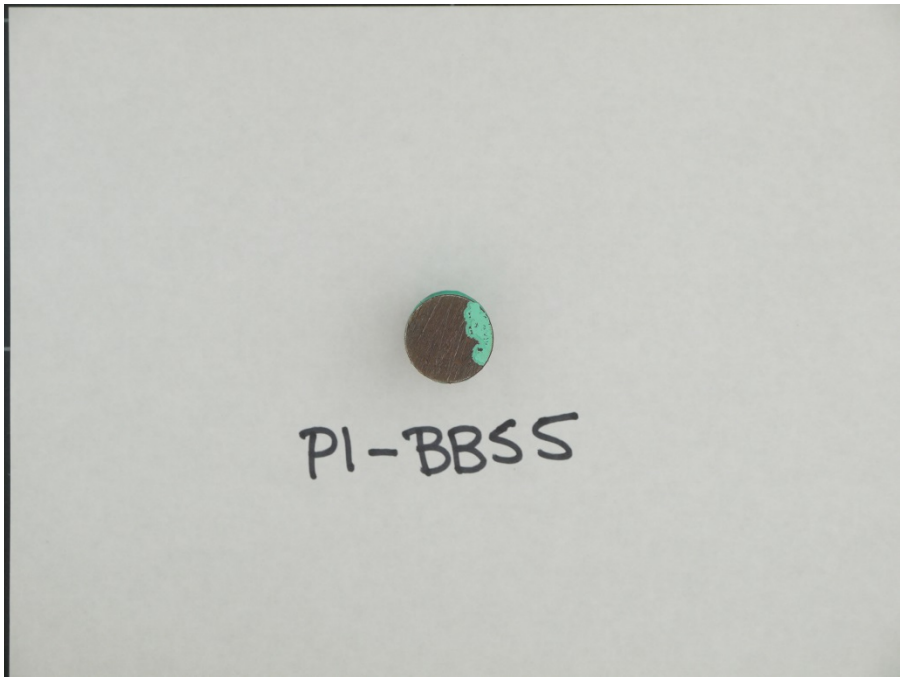


Specimens P1-BBN1 and P1-BBN2

Specimens P1-BBN7 and P1-BBN8



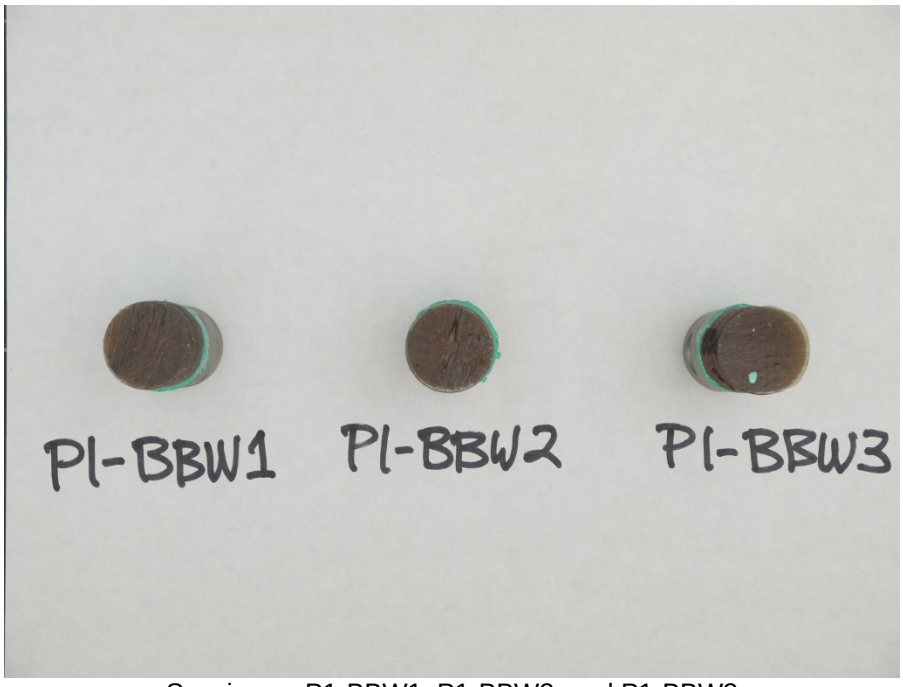
Specimens P1-BBE8, and P1-BBE9, and P1-BBE10



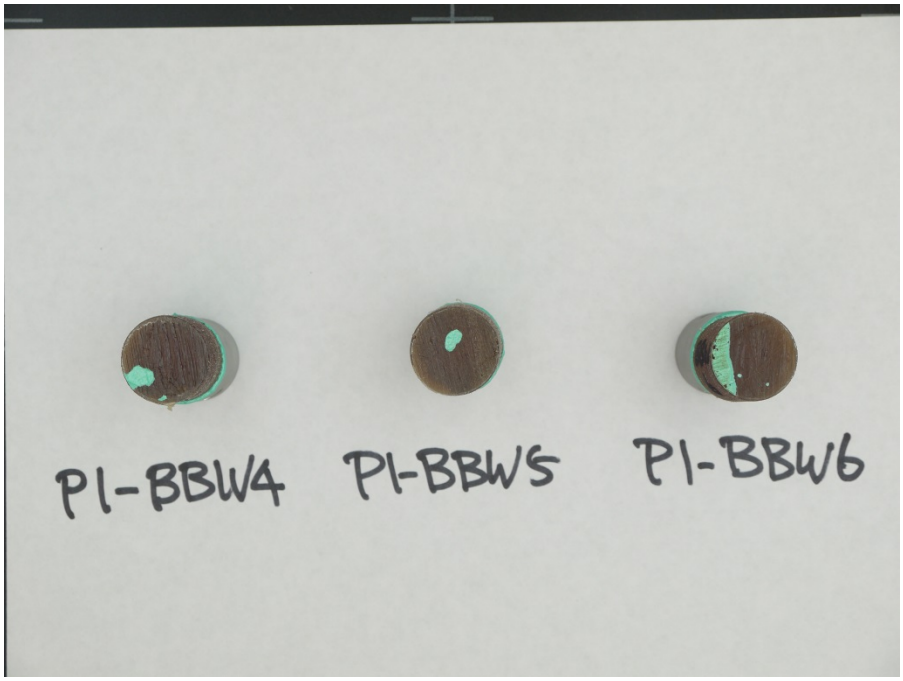
Specimen P1-BBS5

Specimen P1-BBS9

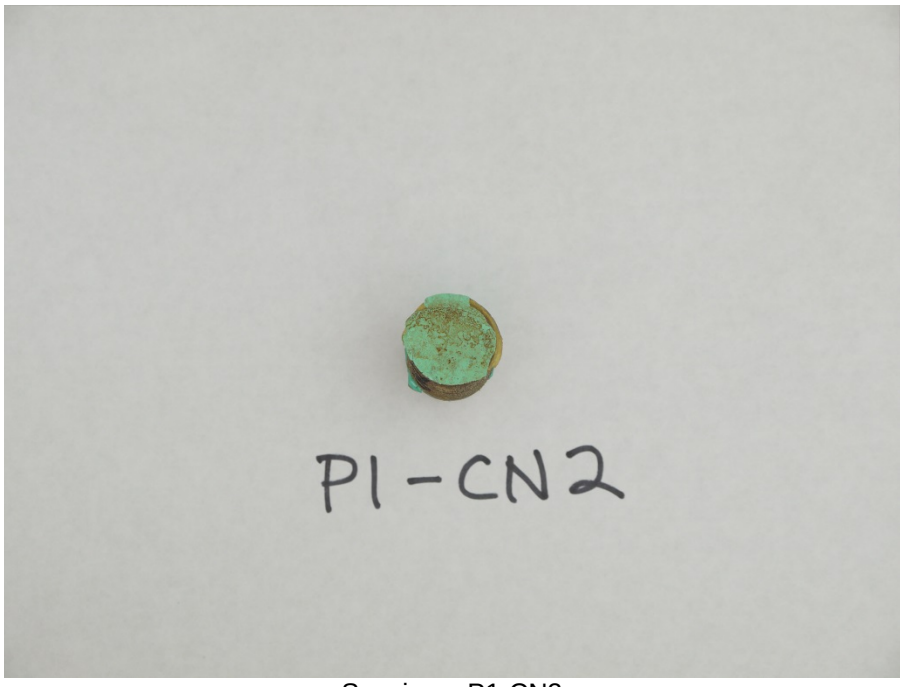
Specimens P1-BBS13, P1-BBS14, and P1-BBS15



Specimens P1-BBW1, P1-BBW2, and P1-BBW3



Specimens P1-BBW4, P1-BBW-5, and P1-BBW6



Specimen P1-CN2

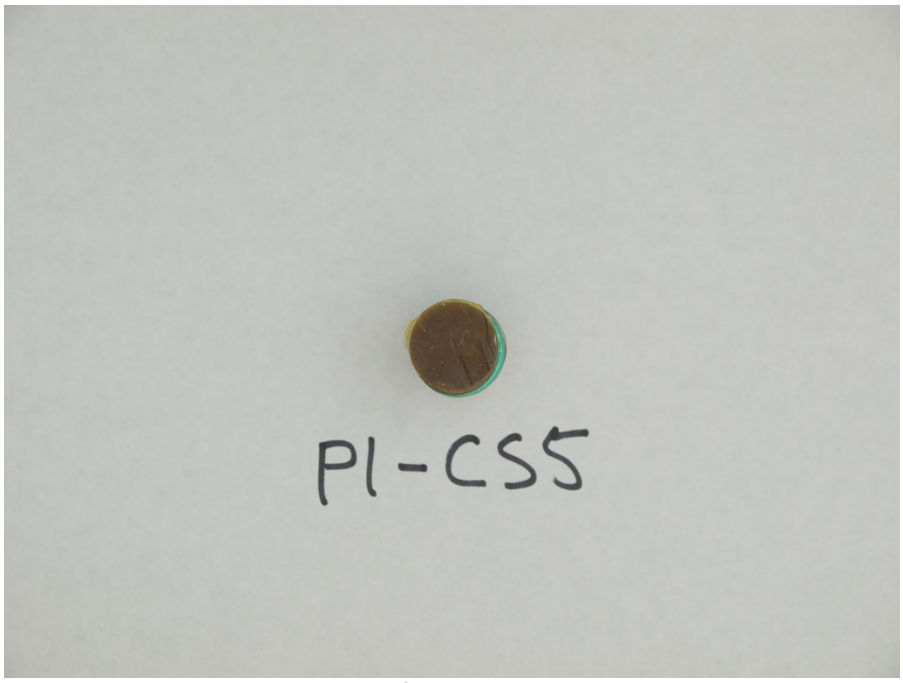
Specimens P1-CN4, P1-CN5, and P1-CN6

Specimens P1-CE4 and P1-CE6

Specimens P1-CE7 and P1-CE8

Specimens P1-CE9 and P1-CE10

Specimens P1-CS2, P1-CS3, and P1-CS4

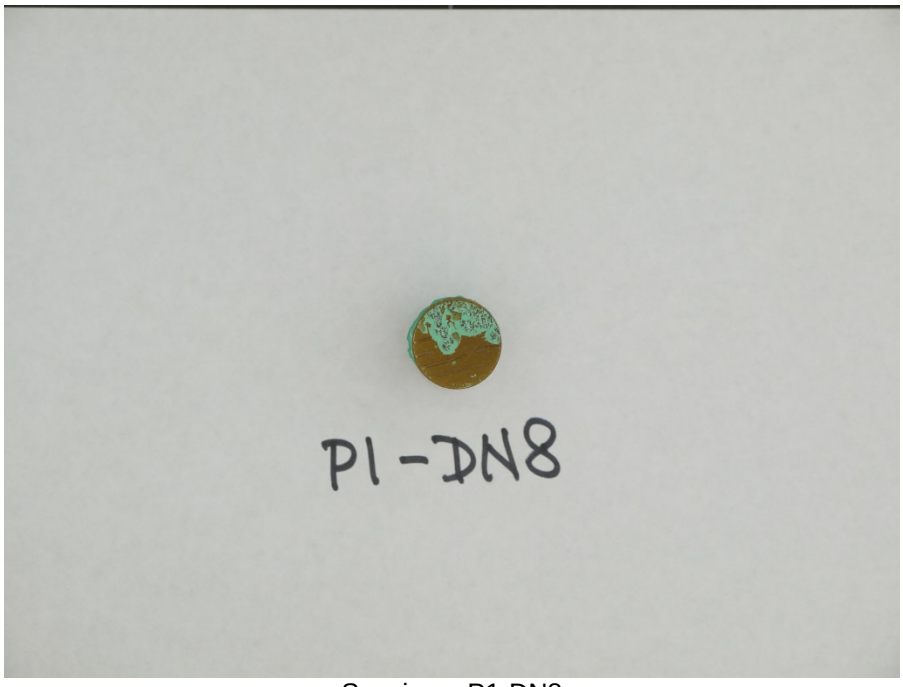


Specimen P1-CS5

Specimens P1-CW6, P1-CW7, and P1-CW8

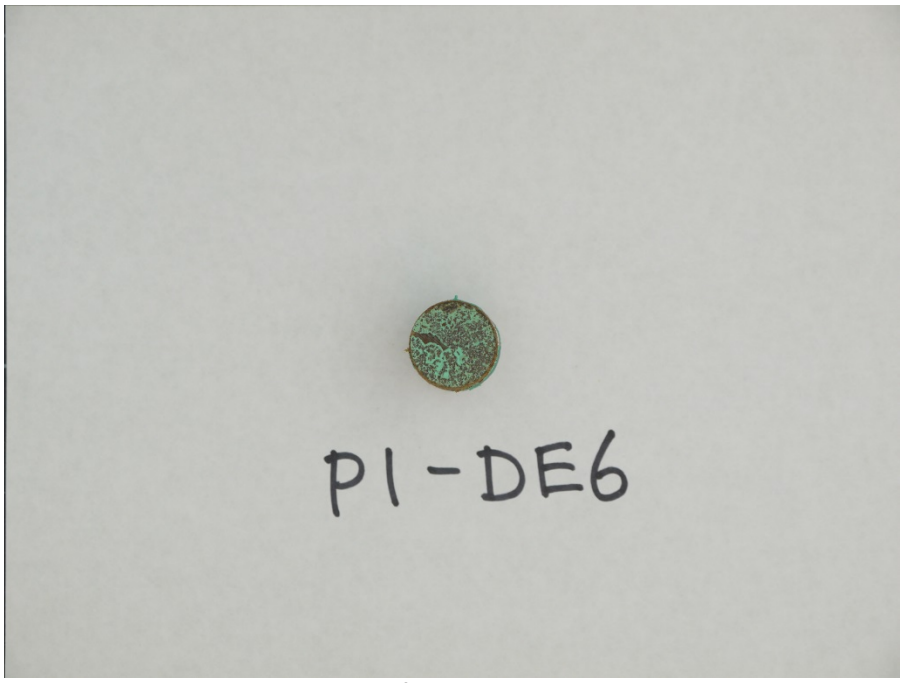
Specimens P1-CW10 and P1-CW11

Specimens P1-DN1, P1-DN2, and P1-DN3

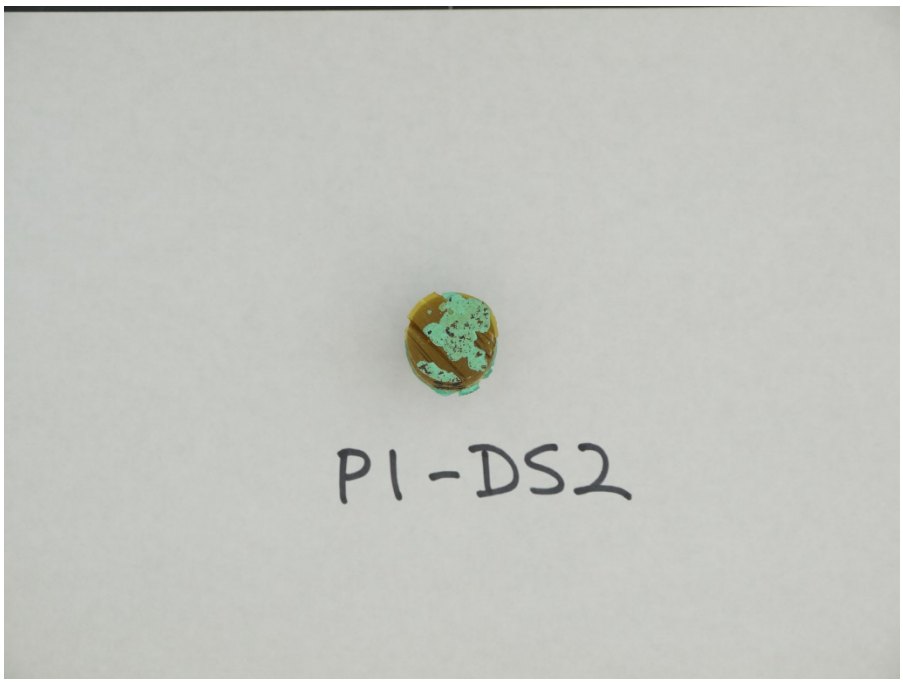


Specimen P1-DN8

Specimens P1-DE2, P1-DE3, and P1-DE4



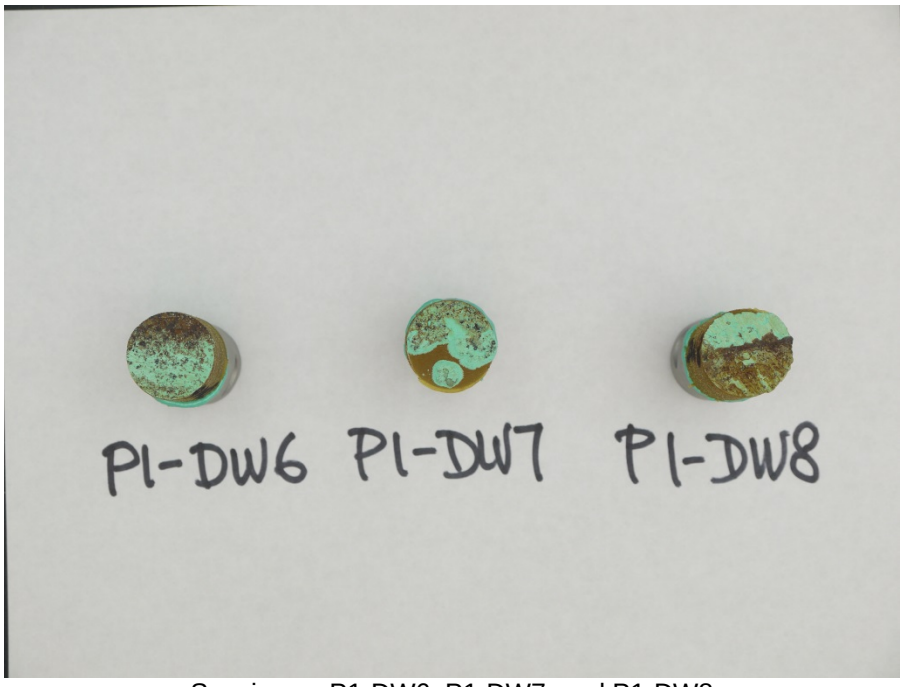
Specimen P1-DE6



Specimen P1-DS2

Specimens P1-DS5, P1-DS6, and P1-DS7

Specimens P1-DW2, P1-DW4, and P1-DW5

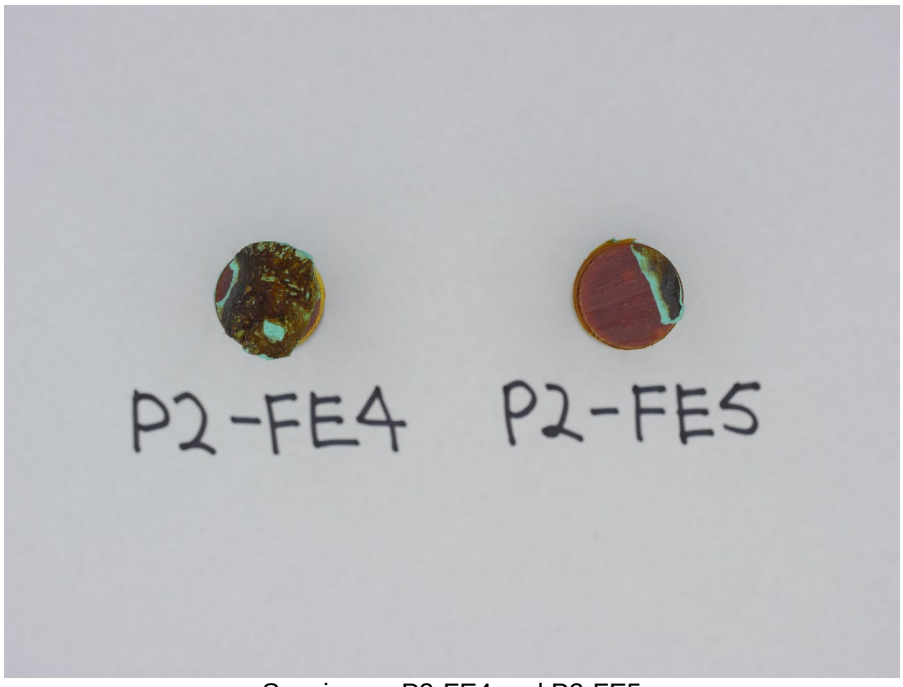


Specimens P1-DW6, P1-DW7, and P1-DW8

Specimens P2-FN1 and P2-FN2

Specimens P2-FN3 and P2-FN5

Specimens P2-FE1 and P2-FE2



Specimens P2-FE4 and P2-FE5

Specimens P2-FS1 and P2-FS2

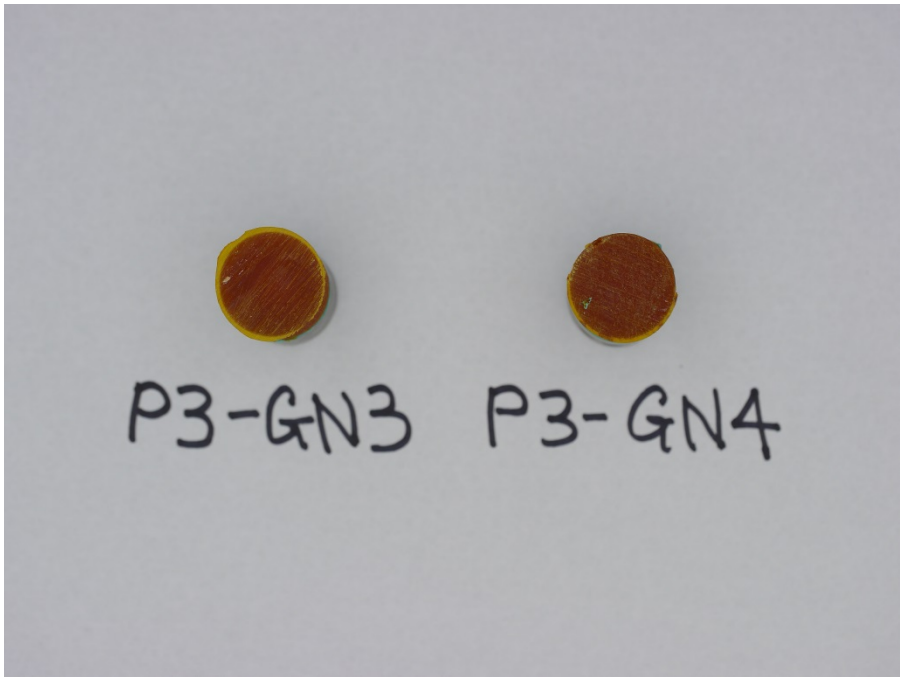
Specimens P2-FS3, P2-FS4, and P2-FS5

Specimens P2-FW1 and P2-FW2

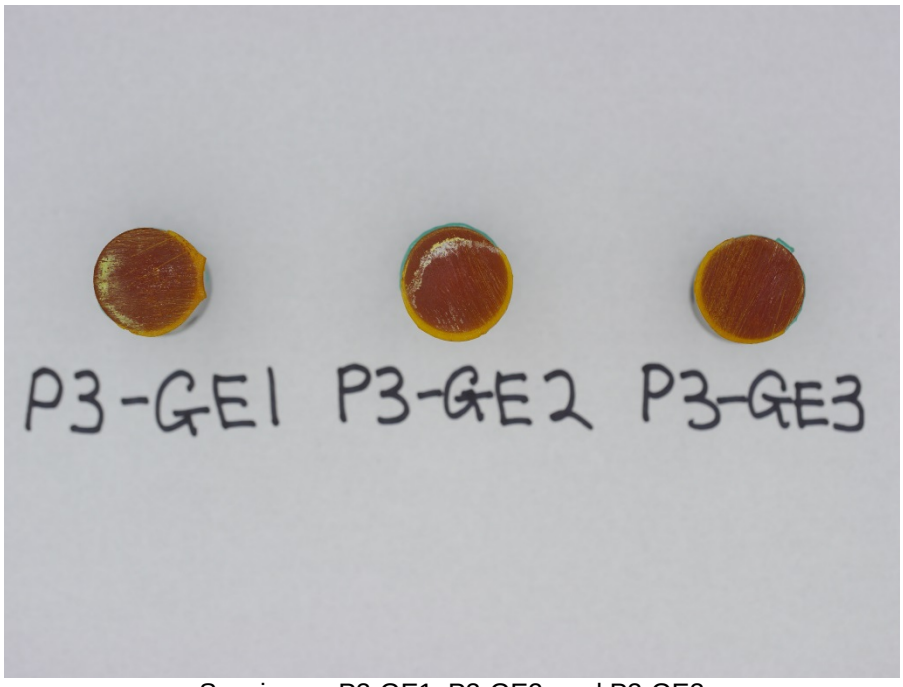
Specimens P2-FW3 and P2-FW5

Specimens P2-FW6 and P2-FW7

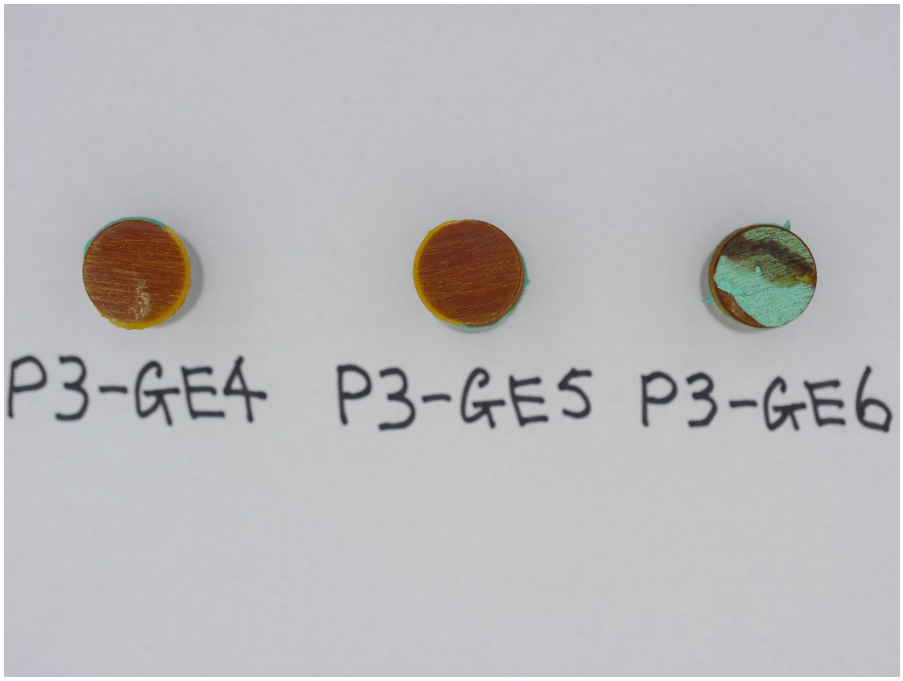
Specimens P3-GN1 and P3-GN2



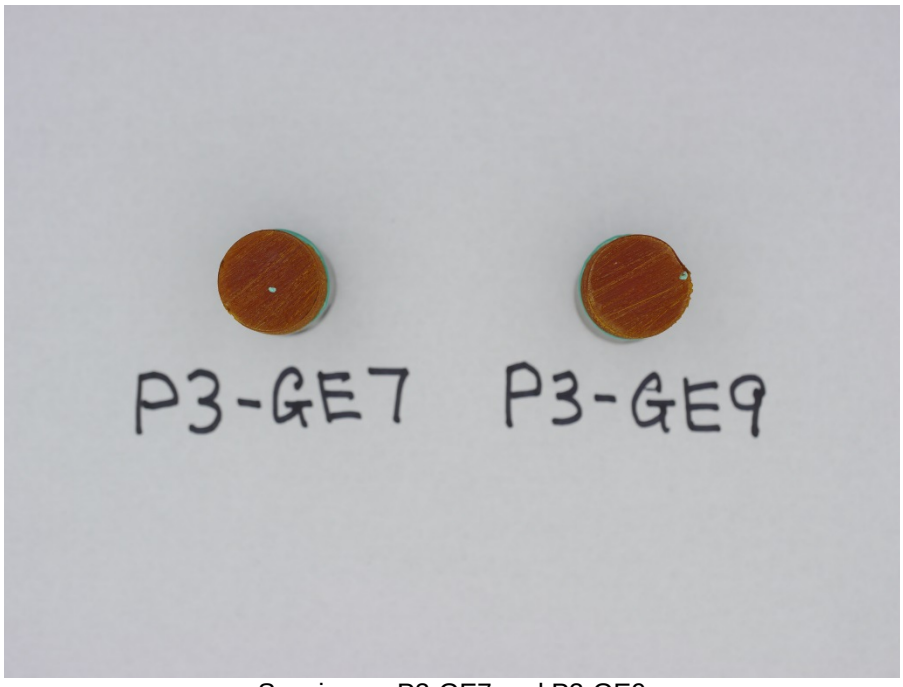
Specimens P3-GN3 and P3-GN4



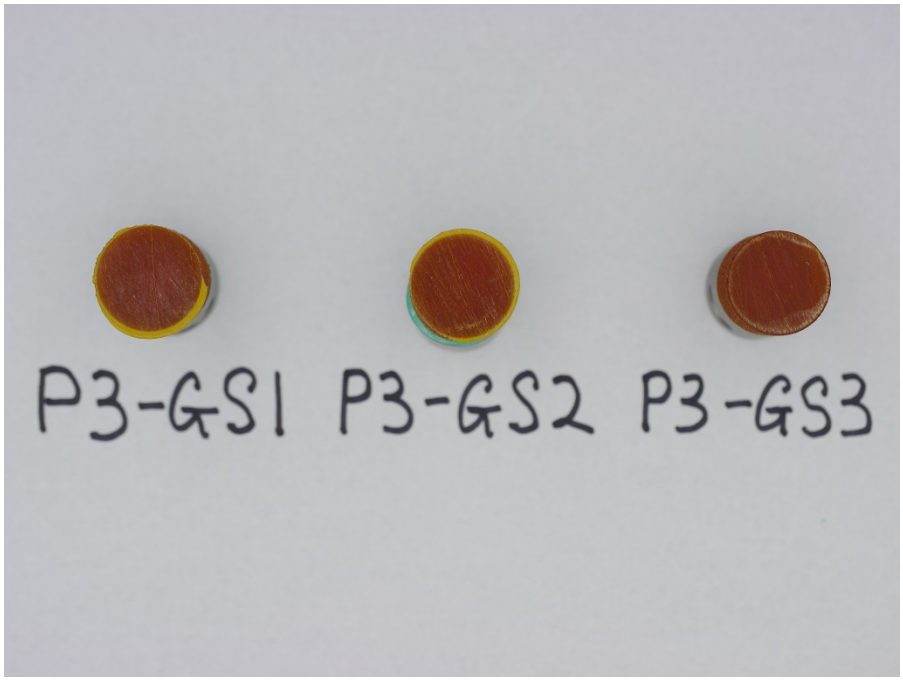
Specimens P3-GE1, P3-GE2, and P3-GE3



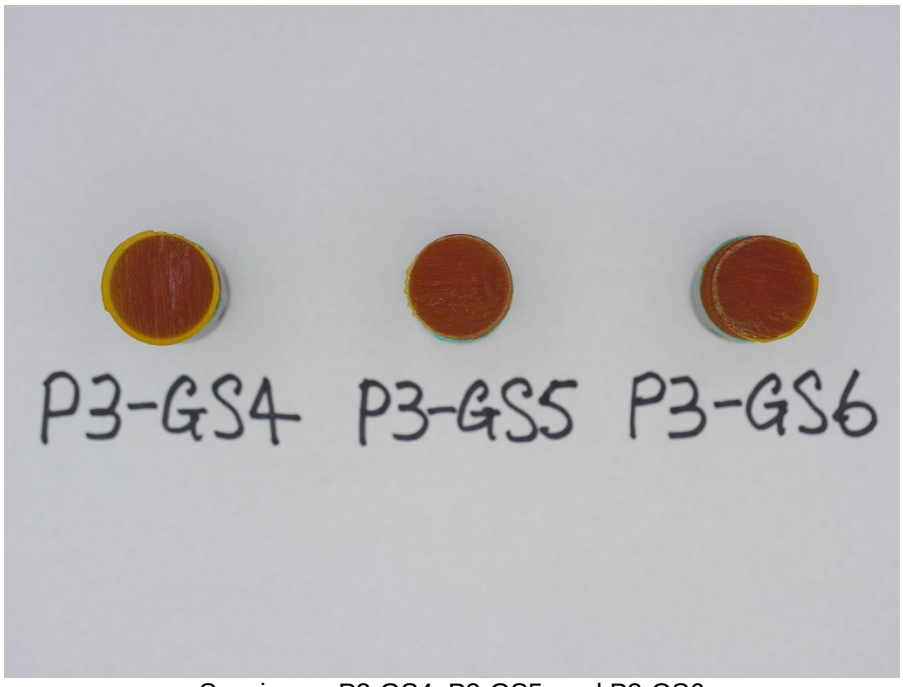
Specimens P3-GE4, P3-GE5, and P3-GE6



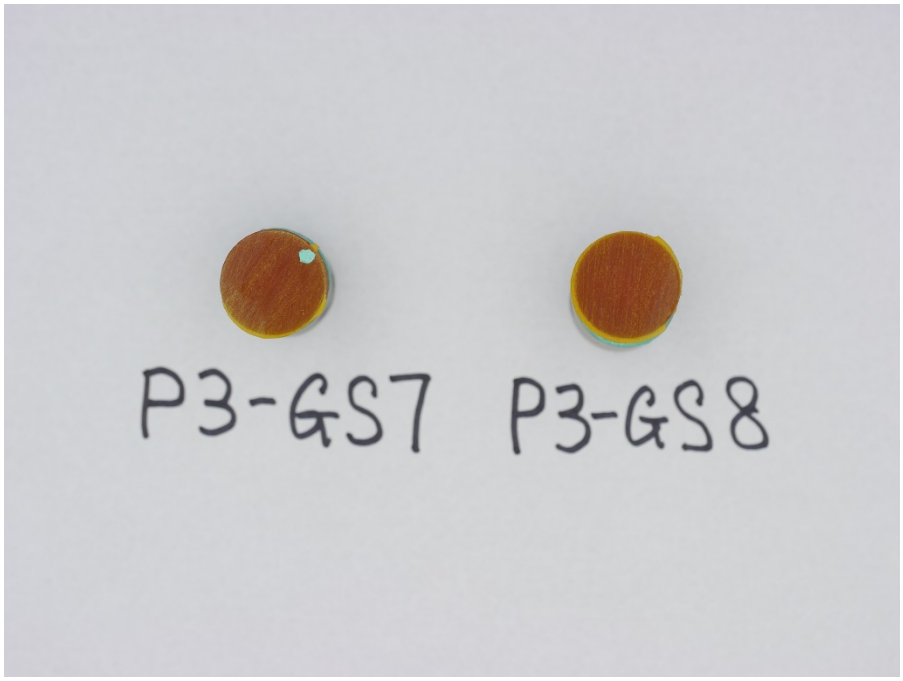
Specimens P3-GE7 and P3-GE9



Specimens P3-GS1, P3-GS2, and P3-GS3

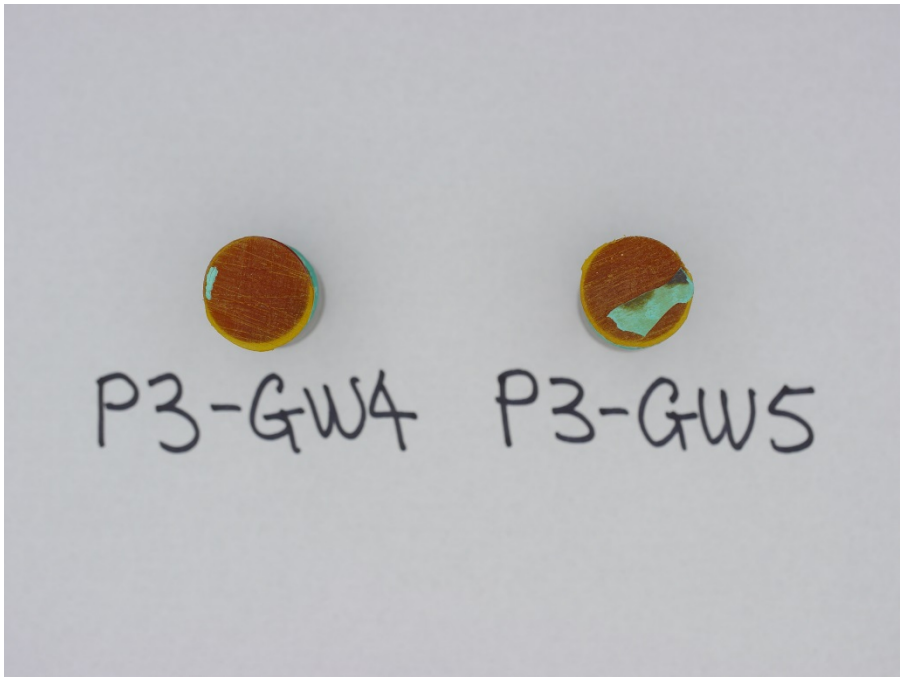


Specimens P3-GS4, P3-GS5, and P3-GS6



Specimens P3-GS7 and P3-GS8

Specimens P3-GW1 and P3-GW3



Specimens P3-GW4 and P3-GW5