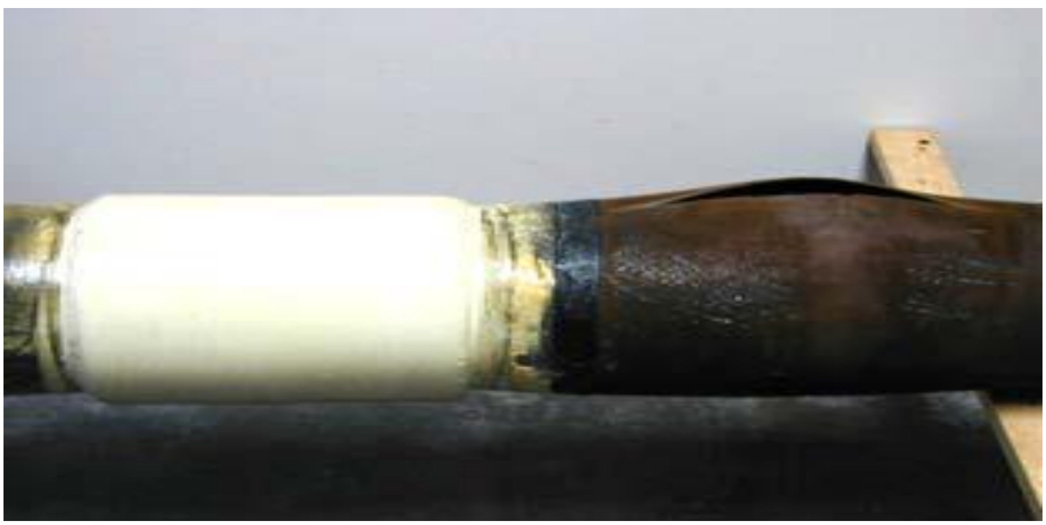
AquaWrap®

Soluciones para tuberías con corrosión

- **Te dará el "peace of mind" que necesitas**
- **Calidad garantizada acompañado con un personal altamente calificado**
- **Cumple con las normas: ASME PCC-2, Art 4.1, DOT 49 Parts CFR192/ 195, ISO/TS 24817, NSF/ANSI Standard 61, ASME B31.4 & ASME B31.8**
- **Todo tipo de geometría, temperaturas, químicos y** aplicación bajo agua.



TECNOLOGIA TOTAL le frece la mejor solución para sus problemas de corrosión. Los sistemas AquaWrap® & GatorWrap® son lo de alta resistencia utilizados para la rehabilitación y reparación de líneas de transporte y distribución afectadas por corrosión o erosión.

Unas de las mayores ventajas sobre los sistemas AquaWrap® & GatorWrap® es su versatilidad ya que pueden ser aplicados en todos los ambientes (bajo agua) y geometrías complejas, tales como: conexiones T, codos, secciones rectas y superficies irregulares y espacios limitados que requieren refuerzo estructural. Las propiedades adhesivas del sistema hacen que el producto pueda ser aplicado en casi todo tipo de sustratos.

Los sistemas AquaWrap® & GatorWrap® están diseñado para proveer la resistencia necesaria, devolviéndole a la tubería las condiciones originales de máxima presión de operación sin necesidad de parar la producción. El sistema esta probados conjunta e independientemente tanto en laboratorios de Los Estados Unidos de América.

A continuación me complace presentarles los ensayos de laboratorio y fichas técnicas relacionadas con los sistemas AquaWrap® & GatorWrap®.

Esperamos poder servirle de inmediato apoyándolo a mitigar sus problemas de corrosión, nosotros ofrecemos la mejor alternativa y los mayores beneficios, ¡déjennos probarlo!

Para mayor información, visítenos en la página web para localizar nuestro representante más cercano o escribanos: tts@tecnologiatotal.net

TABLA DE CONTENIDOS

UKAS MANAGEMENT SYSTEMS

060

WORLD CERTIFICATION SERVICES

Certificate Of Registration

Certificate Number

7222

Date First Registered

20 January 2011

Date Certificate Expires

7 January 2014

This Certificate has been awarded to:

Air Logistics Corporation

925 North Todd Avenue
Azusa, CA 91702
USA

In Recognition of the Organisation's Management System which complies with:

ISO 9001:2008

For the Scope of Activities described below:

The Manufacture and Distribution of Composite Wrapping Materials.

This Certificate has been awarded by

World Certification Services Ltd.

Issued By:

Issue Date: **20 January 2011**

World Certification Services Ltd.
Custom House
52a Mersey View
Brighton-le-Sands
Liverpool, UK

The use of the accreditation mark indicates accreditation in respect of those activities covered by accreditation certificate number 60

MEMBER OF MULTILATERAL IAF RECOGNITION ARRANGEMENT

STRESS ENGINEERING SERVICES INC.
an employee-owned company

13800 Westfair East Drive, Houston, Texas 77041-1101
Phone: (281) 955-2900 Fax: (281) 955-2638 Website: www.stress.com

HOUSTON • CINCINNATI • NEW ORLEANS

March 9, 2009 PN114315CRA

Mr. Franz Worth, P.E.
Air Logistics Corporation
925 North Todd Avenue
Azusa, CA 91702
Phone: 626-633-0294
E-mail: fworth@airlog.com

SUBJECT: Review of Air Logistics Test Program Relative to ASME PCC-2 Requirements

Franz,

Per your request, Stress Engineering Services, Inc. (SES) has reviewed the testing documentation package that you provided and compared the completed tests to the ASME PCC-2 testing requirements. **Table 1** on the attached page was prepared by one of our staff members after reviewing all of the documentation that you provided to us. This documentation included both hard copies, as well as electronic versions of the testing results obtained by numerous third party test labs.

Of the sixteen (16) possible types of tests that are required by ASME PCC-2, your documentation demonstrated that all but two (2) of the listed tests were completed. These included the following:

- Test #9 – Impact performance per Appendix VI of ASME PCC-2 that is required only for composite repair systems used to repair leaking pipes.
- Test #16 – Chemical compatibility that is listed as an optional requirement (ASTM D 543, ASTM C 581, ASTM D 3681, and ISO 10952).

Therefore, of all the mandatory tests that are required for composite repair systems used to provide structural reinforcement (i.e. not the repair of leaking pipes); Air Logistics, Inc. has completed all of the required testing efforts.

It should be noted that SES has made no effort to confirm the validity or accuracy of the reported test results that were provided. Additionally, no attempt has been made to compare test results to the minimum requirements relative to the specified ASME PCC-2 tests.

We have appreciated the opportunity to be of service to you and appreciate the level of detail associated with the provided documentation. Please feel free to contact me if you have any questions or comments related to our review of your test program.

Regards,

Dr. Chris Alexander
chris.alexander@stress.com
Direct phone: 281-897-6504
Cell phone: 281-450-6642

Attachments: ASME PCC-2 test requirement table

Table 1 – Summary of Air Logistics Completed Testing Efforts Relative to ASME PCC-2 Requirements

TEST REQUIREMENTS AND METHOD SUMMARY							
Number	**Property**	**Test Type**	**Detail Properties**	**Minimum Values**	**Testing Performed?**	**Result**	**Test Specification**
1	Tensile Strength	M	Tensile strength, modulus, Poisson's ratio (for leaking pipes and some design cases); strain to failure in both hoop and axial directions	Strain to failure must be greater than 1%	yes	See data sheets	ISO 527, ASTM D 3039
2	In Plane shear modulus	M for leaking pipes only	Modulus only	None	yes	Avg: 0.781 Msi	ASTM D 5379
3	Per ply thickness	M	Thickness per ply	None	yes	see tensile strength data sheets	None, may be determined from the tensile tests above
4	Hardness	M	Barcol or Shore hardness data	None	yes	see tensile strength data sheets	BS EN 59, ISO 868. ASTM D 2583
5	Coefficient of thermal expansion	M	CTE value	None	yes	see data sheets	ISO 11359-2, ASTM E 831
6	Glass transition Temperature	M or use HDT below	Glass transition temperature T_g	None except that this can determine the maximum operating temperature of the composite system	yes	Type 439 Resin: 120 C 71035/73013 Resin: 87 C Sun Glass VE Resin: 105 C	ISO 11359-2, ASTM D 831, ASTM E 1640, ASTM E 6604
7	Heat distortion temperature	M or use T_g Above	Heat distortion temperature HDT	None except that this can determine the maximum operating temperature of the composite system	yes	Aquawrap: >325 F PS Fabric with standard resin: 300 F	ISO 75, ASTM E 2483
8	Adhesion strength	M	Shear strength of composite bond to steel	$4NM/m^2$ (580 psi)	yes	See data sheets	BS EN 1465, ASTM D 3165
9	Impact performance	Leaking pipes only	Low velocity impact performance	Withstand drop test per appendix VI.	no	none	Appendix VI
10	Energy release rate	Leaking pipes only	Toughness parameter, energy release rate gamma	None	yes	56.6 J/m^2	Appendix IV
11	Long term lap shear performance	O	Measurement of lap shear strength after 1000 hour heat exposure (may be wet)	30% of lap shear strength determined per item 8 above..	yes	See data sheets including Adhesion Strength data sheets	Appendix II-2
12	Structural strengthening	M	Wrapped pipe with defect must withstand a short-term pressure test	Wrap must not fail	yes	8200 psig, pass 6900 psig, pass	Appendix III
13	Long term strength	O	Determine long -term (creep-rupture) strength of the wrap by either of three methods	None, note that this test qualifies the wrap pursuant to table 5.	yes	See data sheets	Appendix V and ASTM D 2922
14	Cathodic disbindement	O	Cathodic disbindement	None	yes	No delaminating, blistering, or undercutting	ASTM-G 8
15	Electrical Conductivity	O	Dielectric Strength	None	yes	Avg: 180 volts/mil	ISO 14692 ASTM D 149
16	Chemical Compatability	O	Chemical Compatability	None	informal only	none	ASTM D 543 ASTM C 581 ASTM D 3681 ISO 10952

NATIONAL TESTING STANDARDS INC.
RESEARCH AND TESTING LABORATORIES

Report No. 28184

June 13, 2002

Client: Air Logistics Corp.
925 Todd Ave.
Azusa, CA 91702

Reference: Mr. John Wegner
Purchase Order No. Verbal

Subject: Evaluation of Pipe Coating to Cathodic Disbondment.

Sample Description:

Three sections of coated steel pipe, approximately 2 3/8" in diameter and 30" long, coated with a green polymeric material were submitted by the Client and identified as follows:

1) BP1 6 layers Aquawrap
2) BP3 6 layers Aquawrap
3) Powersleeve

Request:

Evaluate the resistance of the submitted samples to cathodic disbondment when tested in accordance with the procedures set forth in ASTM G-8 for 90 days.

Method:

The submitted samples were tested in accordance with the procedures set forth in ASTM G-8. The samples were examined every 30 days over a total test period of 90 days.

Results:

None of the submitted samples exhibited any evidence of delaminating, blistering, or undercutting. All three samples were returned to the Client for further evaluation.

NATIONAL TESTING STANDARDS

by Lewis F. West





PRCI LONG-TERM STUDY OF COMPOSITE REPAIR SYSTEMS

PN113586CRA

Prepared for

PRCI and Composite Repair Manufacturers

July 2008

STRESS ENGINEERING SERVICES INC.

PRCI LONG-TERM STUDY OF COMPOSITE REPAIR SYSTEMS

PN113586CRA

Prepared for
PRCI and Composite Repair Manufacturers

Prepared by:

Chris Alexander, Ph.D.
Principal

Ron Scrivner
Staff Consultant

July 2008

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PRCI Long-term Study of Composite Repair Systems

Project Summary Document prepared by Stress Engineering Services, Inc.
Prepared for the Composite Repair Manufacturers · July 14, 2008

This summary document provides a brief overview of the program being sponsored by the Pipeline Research Council International, Inc. (PRCI) for studying the long-term performance of composite repair systems used to reinforce damaged high pressure carbon steel pipelines. The official title of this PRCI study is *Evaluating the Long-Term Performance of Composite Systems for the Repair of Corrosion and Mechanical Damage.* Discussions associated with this program have taken place over the past 5 years and PRCI members voted in 2007 to execute the program with funding being allocated for 2008.

This document specifically outlines the details associated with the test samples involved in testing. The details provided herein are directly related to discussions that took place as part of the kick-off meeting held at Stress Engineering in Houston, Texas on Wednesday, June 11, 2008.

Project Background

The objective of this program is to evaluate the long-term performance characteristics of the composite repair systems used to repair high pressure transmission gas and liquid pipeline systems. This program involves two phases of study: Phase A is a state of the art assessment including surveys of industry, manufacturers, and literature reviews, while Phase B involves full-scale destructive testing of pipelines with simulated corrosion buried for specific periods of time and removed for burst testing.

Phase A – State of the Art Assessment: The primary focus of this phase of the program is to catalog and survey the performance of available composite repair systems via two paths. As a starting point, a review of the state of the art will be provided. A catalog of manufacturers, their testing results and performance data along with a second survey of the industry experience with composite repair systems will be gathered. Particular attention will be paid to failure histories if they exist. With the large number of composite systems available in the market, industry has difficulty in determining which ones are suitable for the intended service. Since composite repair systems have been approved for use by regulators many potential suppliers have made their products available to industry. While the first entry into the market was tested extensively under the watch of industry and regulators, subsequent potential suppliers have not been scrutinized as closely. Some have performed extensive testing to ensure the performance of their products, while others have not been as thorough. The intent of this effort is to develop a single reference for the composite repair systems that includes a review of the state of the art along with results of all testing performed by the manufacturers and independent laboratories. Knowledge of system failures is also desirable if this information can be obtained from the pipeline industry.

Phase B – In Situ Full-scale Long-term Testing Many pipeline companies use composite repair systems as part of their pipeline maintenance programs for temporary or permanent repairs. For permanent repairs up 50 years, no in situ long-term performance data is available at the present time. For temporary repairs, the data are conservative and penalize defects that could be repaired for a longer-use period. While several operators have performed limited evaluations of the repair technologies, others have elected to trust data and sales-oriented information provided by the manufacturers. To date the only published industry-wide research has been a comprehensive program funded by the Gas Research Institute to assess the performance of the Clock Spring repair system for steel pipelines and involved accelerated tests independently assessing the adhesive and composite. However, this work is over ten years old and did not incorporate long-term testing on buried repair units. Several in-service failures of composite repair systems have reportedly taken place, primarily rooted in failure of the adhesives, poor installation techniques, and development of corrosion beneath the repairs. Short and long-term performance assurance is needed to assess the longevity of the current repair systems. The primary focus of the present program is to confirm the performance of actual composite repair systems on pipes subject to in situ service conditions including cyclic internal pressure, cathodic protection, and environmental soil effects. This will be accomplished by conducting performance evaluations of the current composite repair technologies that have been employed to repair corrosion, dents, and mechanical damage. The desired solution is for industry to avoid replacing perfectly good composite repairs due to a lack of engineering data to support their longevity. This program will also provide a greater understanding about the capabilities and limitations in the short and long term use of composite materials to repair pipelines.

Each manufacturer will be contacted about completing a survey on aspects associated with their particular composite repair system. Included in this survey will be questions regarding their experiences.

General Description of Project Execution

The following general activities will be completed as part of this study.

<u>Activities in the first year of the study will include the following activities.</u>

- Utilize the test matrix selected by the project team including
    - 12.75-inch x 0.375-inch, Grade X42 pipe.
    - Machine corrosion areas with depths of 40%, 60%, and 75% of the pipe's nominal wall with a dimension of 8 inches axially and 6 inches circumferentially.
    - Weld end caps to sample.
    - Sandblast area required for installation.
    - Measure wall thickness in machined corroded region
    - Pressurize samples to induce 90% of the minimum specified yield strength in corroded region (e.g. 556 psi generates stress of 37.8 ksi, which is 90% of 42 ksi, in the 75% corroded region).
    - Install strain gages in machined corroded region.
- Have composite repairs installed by each manufacturer. <u>Each manufacturer should provide to Stress Engineering Services, Inc. a calculation package showing how the repair thickness was determined for each of the three corroded samples.</u>
- Install strain gage on outside surface of composite materials for selected samples.
- Perform the Year 0 (base case) burst tests.
- (OPTION) Coat outside of composite repairs (<u>each manufacturer is responsible for doing this on their repair systems including supplies and personnel</u>).
- Excavate region of SES Waller Test Lab where pipes are to be buried with a target depth for having 18 inches of cover on top of pipe.
- Bury pipe samples as appropriate and connect the pressure system, cathodic protection system, and the data acquisition system for monitoring strain beneath the repairs.
- Pressure cycle and blow down the test samples at the designated periods of time. Record strain gage data monthly during periods of pressure application.

Activities in Years 1 through 3 will include the following activities.

- Pressure cycle and blow down the test samples at the designated periods of time. Record strain gage data monthly. Monthly pressure cycling will include one blow-down pressure to psi and 75 cycles from 36% to 72% SMYS.
- Remove pipe samples and perform burst tests at the ends of Year 1, 2, and 3.
- For those companies participating in the three year study, a total of 12 samples will be fabricated with three samples for each repair being pressurized to failure at 0, 1, 2, and 3 years.

The buried pipes will be monitored over a three-year period. The samples will be cycled once per month (e.g. 75 cycles at 50% MAOP) and blown down and then re-pressurized (e.g. 1 cycle at 100% MAOP) once every month. This combination of pressure cycles is considered to be an aggressive representation of actual pressure conditions for a gas pipeline system over a 50 year period. At the end of each subsequent year (1, 2, and 3) one set of three (3) samples will be removed from the buried soil environment, documented, and then burst tested. For those manufacturers who opt for the 10-year study, additional samples will be fabricated for burst testing at 5, 7.5, and 10 years. For this extended period of testing an additional nine (9) samples will be required for each repair system.

The pipe geometry and grade used in this study will be 12.75-inch x 0.375-inch, Grade X42 pipe with a rectangular corrosion patch that measures 8 inches (longitudinally) by 6-inches (circumferentially). The depths of corrosion to be studied include 40, 60, and 75% of the pipe's nominal wall thickness. The geometry for the machined corrosion region is shown in **Figure 1**.

Strain gages will be installed at specific locations that include the corrosion region beneath the repair, on the base pipe, and on top of the composite material. **Figure 2** shows the layout for these samples. Each sample will be 8 feet in length and include welded end caps with 1-inch NPT pressure port fittings.

Once the samples are fabricated, those samples that are designated for burial will be shipped to the test site. **Figure 3** shows the general layout for the buried test samples. As noted, each group of test samples includes a set of three. This figure is drawn as if three manufacturers will participate for a three year period, while another three manufacturers have elected to participate for the 10-year testing period (a total of six participants are illustrated in this figure).

Activities in Years 3 through 10 will include the following activities.

- This phase of work is a continuation of efforts completed as part of the 3 year study.
- Pressure cycle and blow down the test samples at the designated periods of time. Record strain gage data monthly.
- Remove pipe samples and perform burst tests at the ends of Year 5, 7.5, and 10.
- For those companies participating in the ten year study, a total of 21 samples will be fabricated with three samples for each repair being pressurized to failure at 0, 1, 2, 3, 5, 7.5, and 10 years.

Program Specifics

This section of the package is provided to give specific details on what will be expected from each manufacturer and what each manufacturer can expect during their interactions with SES. Of particular note is the schedule. The current schedule is based on the assumed availability of each manufacturer and currently-scheduled SES staff. It is important that each manufacturer review their allotted time on the schedule and make the necessary arrangement including personnel and supplies for completing all of their repairs (i.e. 12 samples for the 3-year study and 21 samples for the 10-year study participants). Each manufacturer will only be given one week for making their respective repairs.

General schedule

- June/July/August
  - Purchase pipe materials
  - Machine simulated corrosion in pipe samples
  - Sandblast pipes
  - Install strain gage
- September/October/November
  - Make repairs (coordinated scheduling)
  - Perform round of Year 0 burst tests (3 per manufacturer)
  - Prepare buried pipe test site and facility
  - Bury pipe samples (all pipes will be buried at the same time)
  - Connect all required instrumentation, CP systems, and pressure equipment

Listed below are the specifics weeks during which manufacturers will be invited to SES facilities to make repairs. Each manufacturer is expected to provide enough materials and personnel to complete all repairs in a one week period. The numbers shown in parentheses correspond to the number of samples that will be required from each respective manufacturer (12 for the 3-year study and 21 for the 10-year study). Additionally, if a manufacturer would like to have their repair system coated prior to burial, they will be responsible for doing this including providing materials and personnel for doing so.

Fabrication Weeks

Week of July 14	Inspect pipe and cut pipe (1,440 feet of pipe purchased)
Week of July 21	Start machining work
Week of July 28	Start welding end caps and continue machining
Week of August 4	Continue welding end caps and machining (33 complete)
Week of August 11	Continue welding end caps and machining
Week of August 18	Continue welding end caps and machining (66 complete)
Week of August 25	Continue welding end caps and machining
Week of September 1	Continue welding end caps and machining (99 complete)
Week of September 8	Continue welding end caps and machining
Week of September 15	Continue welding end caps and machining (132 complete)
Week of September 22	Continue welding end caps and machining
Week of September 29	Continue welding end caps and machining (165 complete)

Installation Weeks

Week of September 8	Clock Spring (12)	Armor Plate (21)
Week of September 22	Air Logistics (12)	Citadel (21)
Week of October 6	Pipe Wrap (12)	EMS (21)
Week of October 13	Wrap Master (12)	T.D. Williamson (21)
Week of October 20	Walker Technical Resources (12)	3X Engineering (21)

Burst Test Weeks (30 total samples for 10 manufacturers)

Week of October 13	Burst testing
Week of October 20	Burst testing (continued)
Week of October 27	Burst testing (continued)
Week of November 3	Burst testing (continued)

Sample Burial Installation Weeks

Week of October 6	Installation work (site preparation work and other activities)
Week of October 13	Installation work (continued)
Week of October 20	Installation work (continued)
Week of October 27	Installation work (continued)
Week of November 3	Installation work (continued)

Testing Kick-off Weeks

Week of November 10	Pressurize samples and check for leaks and that strain gages are reading properly
Week of November 17	Bury samples, check CP system, and make sure pressure is maintained

<u>Test Sample Preparation</u>

Provide below is a list of specific details associated with each test sample.

- Fabrication of test samples
  - Years of participation:
    - Three (3) year study participants: Four (4) test periods: 0, 1, 2, and 3 years
    - Ten (10) year study participants: Seven (7) test periods: 0, 1, 2, 3, 5, 7.5, and 10 years
  - Three (3) duplicate samples of each repair system
    - 12 samples per manufacturer for 3-year study participants
    - 21 samples per manufacturer for 10-year study participants
  - Machine corrosion to specified depths of 40, 60, and 75 percent of the 0.375-inch nominal pipe wall
- Sandblast samples [1]
- Measure wall thickness in machined corroded region
- Install strain gages
- Pressurize samples to induce minimum specified yield (42 ksi) in corroded region
- Repair samples using composite systems
- Install remaining strain gages as appropriate

<u>Year 0 Burst Tests</u>

- Connect data acquisition (DAQ) system to strain gages and pressure transducer
- Pressurize sample to failure and record data at one scan per second
- Record failure pressures and plot strain as a function of internal pressure for each sample (tabulate maximum strain recorded in repaired region at design pressure and ultimate pressure)

---

[1] After sandblasting, samples will be shipped to SES's air-conditioned test facility and placed inside for installing strain gages. Every effort will be made to permit repairs to be made inside the test lab. This has been SES's typical mode of operation as long as the repair systems do not contain Volatile Organic Compounds (VOCs). Additionally, some of you have requested that sandblasting be performed within a short period of time (e.g. 24 hours) before the repairs are made; however this is not possible with the current schedule and scope of work that includes strain gage installation.

Long-term Burial Study

- Prepare test area by excavating test site
- Connect samples to pressure system, pressure relief valves, CP system, and strain gages to data acquisition system
- Pressure samples to MAOP
- Bury test samples and monitor/pressure cycles monthly (record with DAQ system)
  - Monthly blow down to 0 psi
  - 75 pressure cycles at 50% MAOP (cycle from 36% to 72% SMYS) once per month
- Maintain pressure in samples at 36% SMYS continuously for all periods except when monthly pressure cycling is being conducted
- Remove samples for testing and burst at specified periods of time (e.g. 1, 2, 3, 5, 7.5, and 10 years)
- Review burst failures and report results

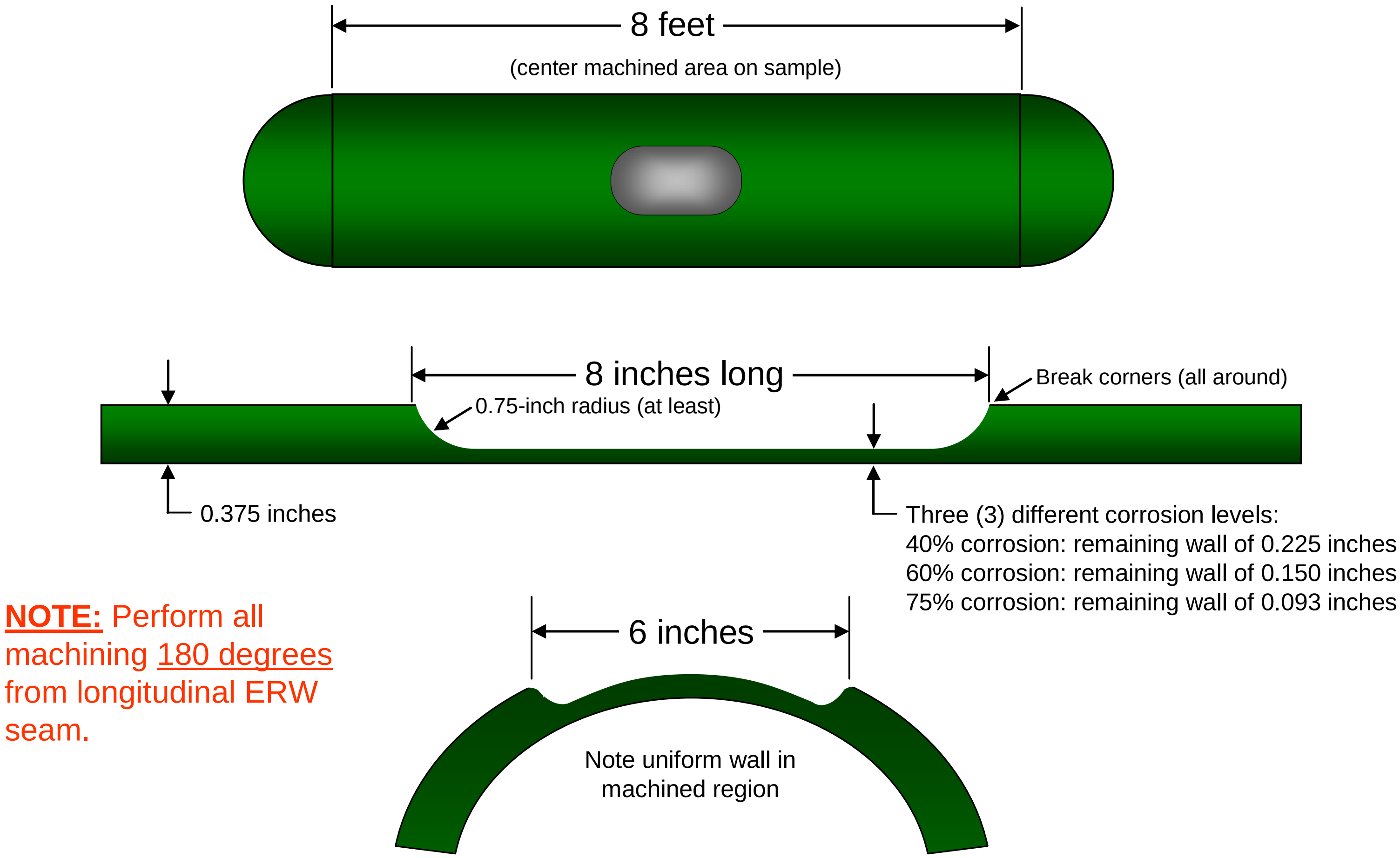
Note that a pressure level of 35% SMYS will be maintained continuously in the pipe samples except during the monthly pressure cycling periods.

Closing Comments

The next several months at Stress Engineering are going to involve a significant amount of work that includes (or has included) purchasing pipe, coordinating machining and fabricating work, sandblasting, pressurizing samples to induce local yielding, installing strain gages, and coordinating with manufacturers time for repair activities.

In anticipation of upcoming events, we request that each manufacturer do the following:

1. Prepare a written design package that details the methods used to determine the required thickness for each corrosion repair depth (i.e. 40, 60, and 75% of the nominal pipe wall thickness). This should be submitted to SES prior to your scheduled installation repair time.
2. Determine and gather the required amount of material for making repairs on all of your test samples (9 samples for the 3-year participants and 21 samples for the 10-year participants).
3. Make sure you have enough staff available in Houston to make all repairs in one week. There will be no exceptions as we have limited space and resources for making these repairs.
4. You are welcome to join us for the times during which we will be pressurizing your test samples to failure. As the time approaches, we will issue a schedule detailing when these burst tests will be made. Based on projected schedule estimations, these will be done between the weeks of October 13 and November 3.



Details on machining

(machined area is 8 inches long by 6 inches wide)

Figure 1 – Details on machining corrosion in 12.75-inch x 0.375-inch, Grade X42 pipe
(target corrosion depth as a percentage of the pipe's nominal wall thickness as shown)

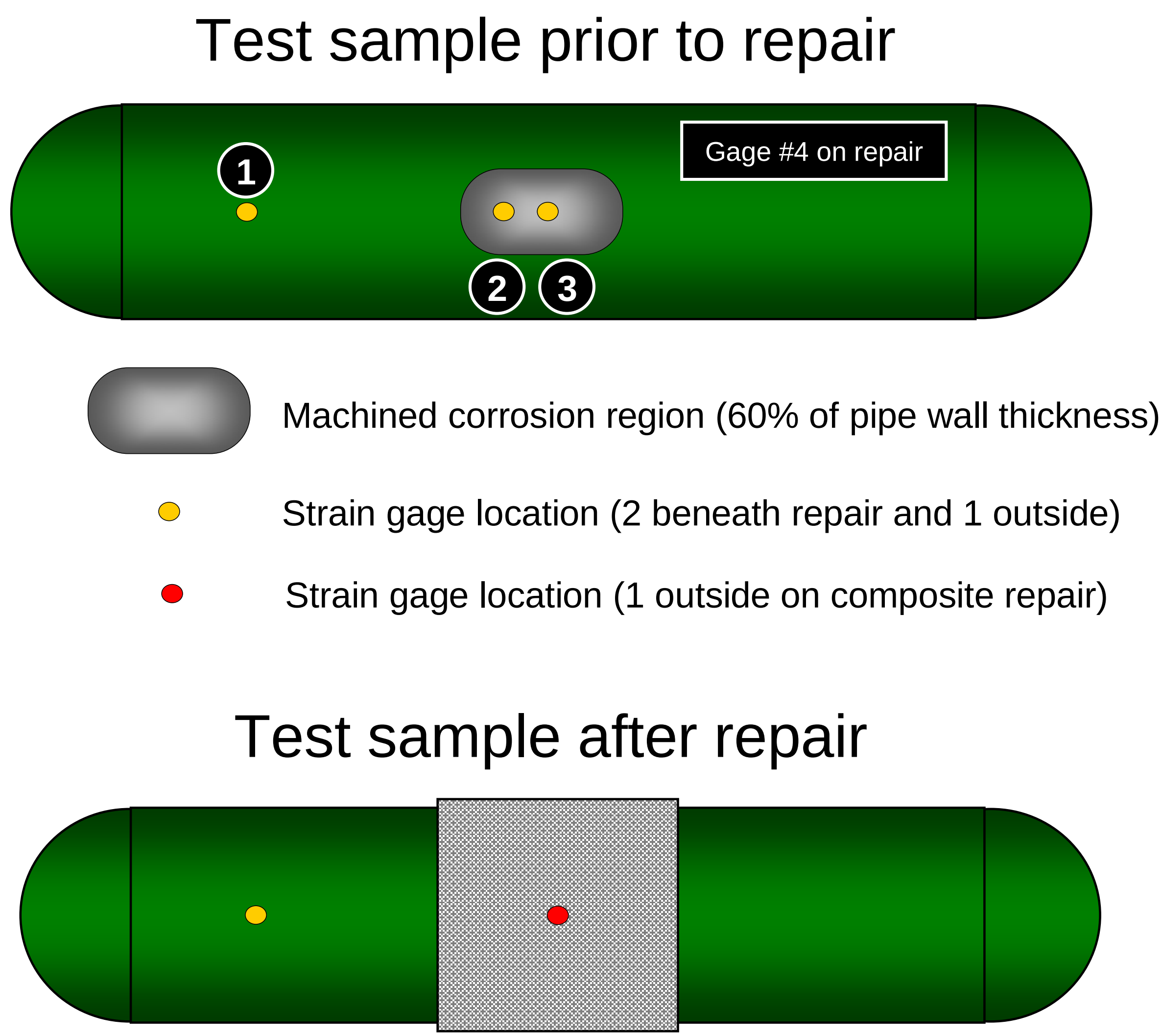


Figure 2 – Test sample layout including strain gage locations

NOTE: The plan for strain gauging is that all samples will have at least one bi-axial gage installed beneath the composite repair (Gage #3 in above figure); however, only one-third of all samples will have all four strain gages installed as shown above. In having strain gages installed beneath all repairs, this will permit SES to monitor the critical information regarding load transfer from the pipe to the composite as a function of time. Every effort will be made to ensure survival of the strain gages, although there are no guarantees that these gages will remain on the samples during all stages of testing.

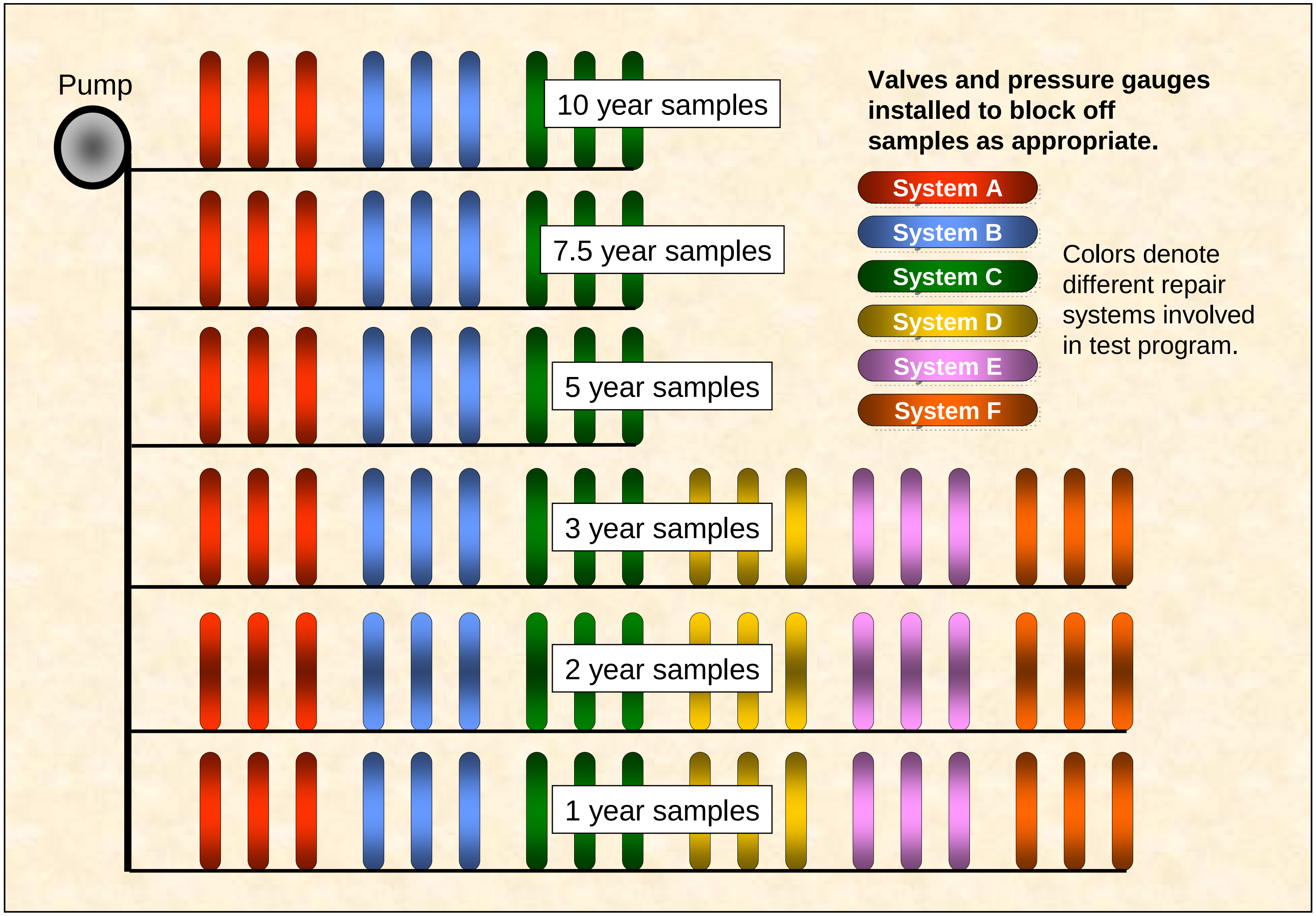


Figure 3 – Layout for buried pipe samples

(the layout shown above only includes six total repair systems: three for the 3-year study and three for the 10-year study)

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PRCI Co-sponsored Long-term Composite Repair Study

Year 0 Burst Test Progress Report (December 2008)

Prepared by: Chris Alexander (chris.alexander@stress.com and 281-897-6504)
Prepared for: Air Logistics (3-year study participant)
Subject: Test results for Year 0 burst test involving 12.75-inch x 0.375-inch, Grade X42 pipe. Composite repair of three samples having corrosion depths of 40, 60, and 75% relative to nominal pipe wall thickness.

Burst and Strain Gage Results

The table below lists the results recorded during the burst tests. Consider the following points reviewing the provided data.

- The pressure levels for the pipe are MAOP = 1,778 psi and SMYS = 2,470 psi.
- Refer to **Figure 1** on the attached page for the strain gage locations. Gage #4 on the outside of the repair is lined up with Gage #3 on the machined corrosion region.
- The strain gage results are in units of microstrain ($\mu\varepsilon = 10^{-6}$ in/in). Elastic stress is calculated by multiplying strain by the material's elastic modulus (i.e. 30 Msi for steel). For example, if the strain in the steel is 1000 με, the stress is calculated to be 1000 με x 30 Msi = 30,000 psi. For the composite material, the elastic modulus will be less than steel.
- The average measured composite thickness values for the 40, 60, and 75 percent samples were 0.690, 0.750, and 0.900 inches, respectively.

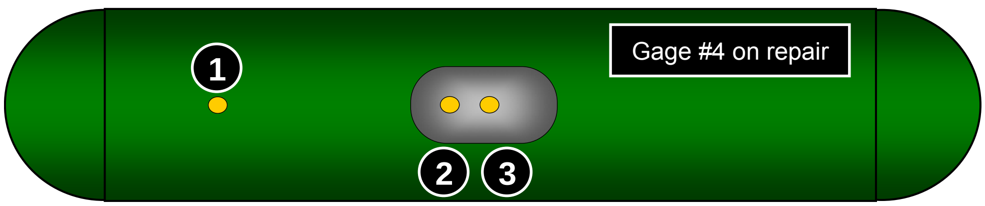
Corrosion Depth (%)	Pressure Level	Hoop Strain Under Repair (center)	Hoop Strain Under Repair (offset)	Hoop Strain on Outside Repair	Hoop Strain on Base Pipe	Burst Pressure (psi)
40	MAOP	1,167	1,197	675	815	4,147
	SMYS	1,999	2,088	1,005	1,084	
60	MAOP	1,879	1,894	919	924	4,090
	SMYS	3,714	3,734	1,809	1,498	
75	MAOP	2,999	3,227	1,597	864	4,291
	SMYS	5,224	5,787	2,661	1,197	

Photographs

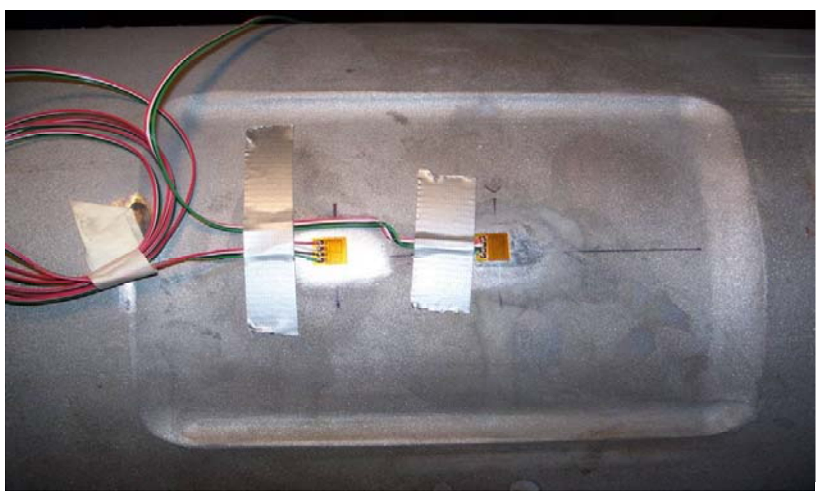
General comments

All burst test failures occurred outside of the repairs. The recorded strain gage readings were relatively low and would be considered acceptable for design conditions associated with a typical transmission pipeline system

A website has been prepared for this program (www.compositerepairstudy.com). In 2009 we will be contacting manufacturers and pipeline companies to request their participation in completing an on-line survey currently posted on the website. Information from the operator and manufacturer surveys will be important to communicate overall trends associated with using composite materials to repair pipelines. Additionally, it is expected that this website will serve as a communication vehicle for this study in the future.



Location of strain gages installed on the test sample



Photograph of strain gages installed in a machined corrosion region

Figure 1 – Details on strain gage installation

This document prepared by:

Chris Alexander

Dr. Chris Alexander, Principal
Stress Engineering Services, Inc.
December 30, 2008

STRESS ENGINEERING SERVICES INC.

13800 Westfair East Drive, Houston, Texas 77041-1101
Phone: (281) 955-2900 Fax: (281) 955-2638 Website: www.stress.com

HOUSTON • CINCINNATI • NEW ORLEANS • CHICAGO

January 25, 2011 PN113586CRA

Mr. Franz Worth, P.E.
Air Logistics Corporation
925 North Todd Avenue
Azusa, CA 91702
Phone: 626-633-0294
E-mail: fworth@airlog.com

SUBJECT: Long-term Composite Repair Study, Year 1 Burst Results

Franz,

This letter report provides a summary of the burst testing that was performed for the Year 1 by Stress Engineering Services, Inc. (SES).

The test program is attached to this letter report and provides the specific activities completed in the burst test. The Year 1 samples were removed form the burial area at our Waller facility in July, 2010. The three samples (40%, 60% and 75% wall loss) were then pressured to failure while pressure and strain were recorded. The burst pressures for the samples are listed in the table below.

Sample Number	Burst Pressure (psi)
40	4,101
60	4,052
75	4,053

The following figures are provided on the attached pages.

- Figure 1 – Pressure vs. Hoop Strain, 40% Corrosion Sample
- Figure 2 – Pressure vs. Hoop Strain, 60% Corrosion Sample
- Figure 3 – Pressure vs. Elapsed Time, 75% Corrosion Sample
- Figure 4 – Photograph of Failure Location, 40% Corrosion Sample
- Figure 5 – Photograph of Failure Location, 60% Corrosion Sample
- Figure 6 – Photograph of Failure Location, 75% Corrosion Sample
- Figure 7 – Pressure Transducer Calibration Certificate

Please contact me if you have any questions.

Regards,

Chris Alexander, Ph.D.
Chris.alexander@stress.com
(281) 955-2900 (office)

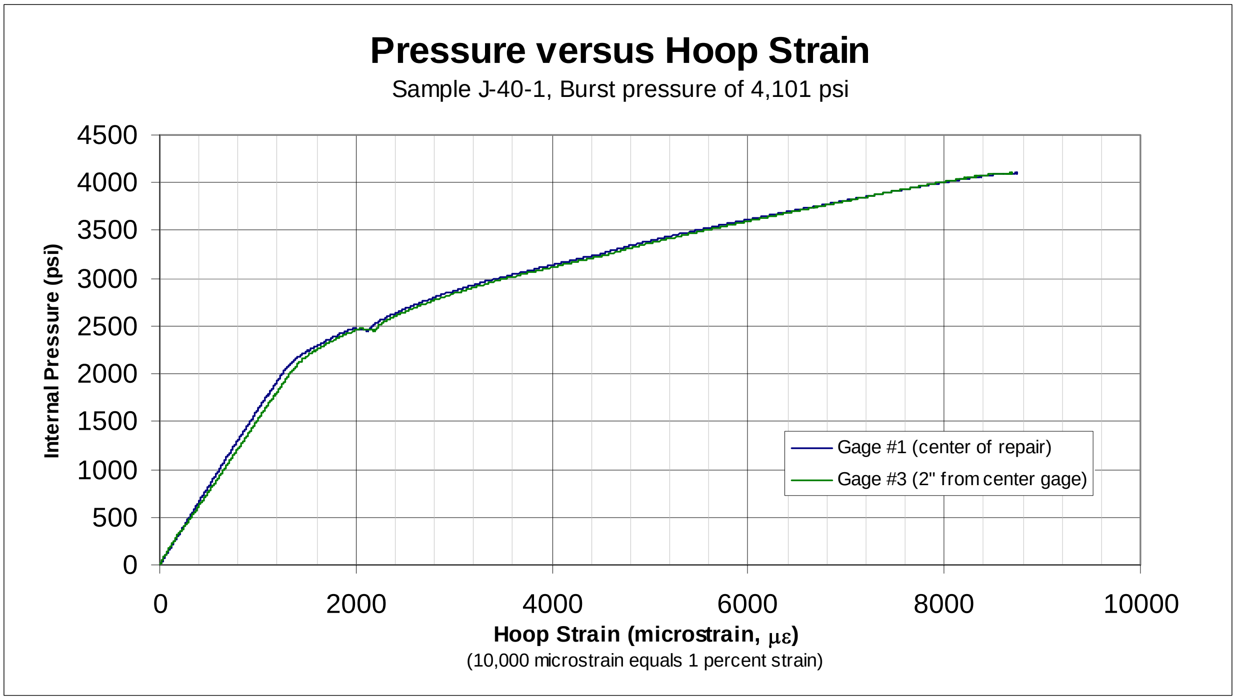


Figure 1 – Pressure vs. Hoop Strain, 40% Corrosion Sample

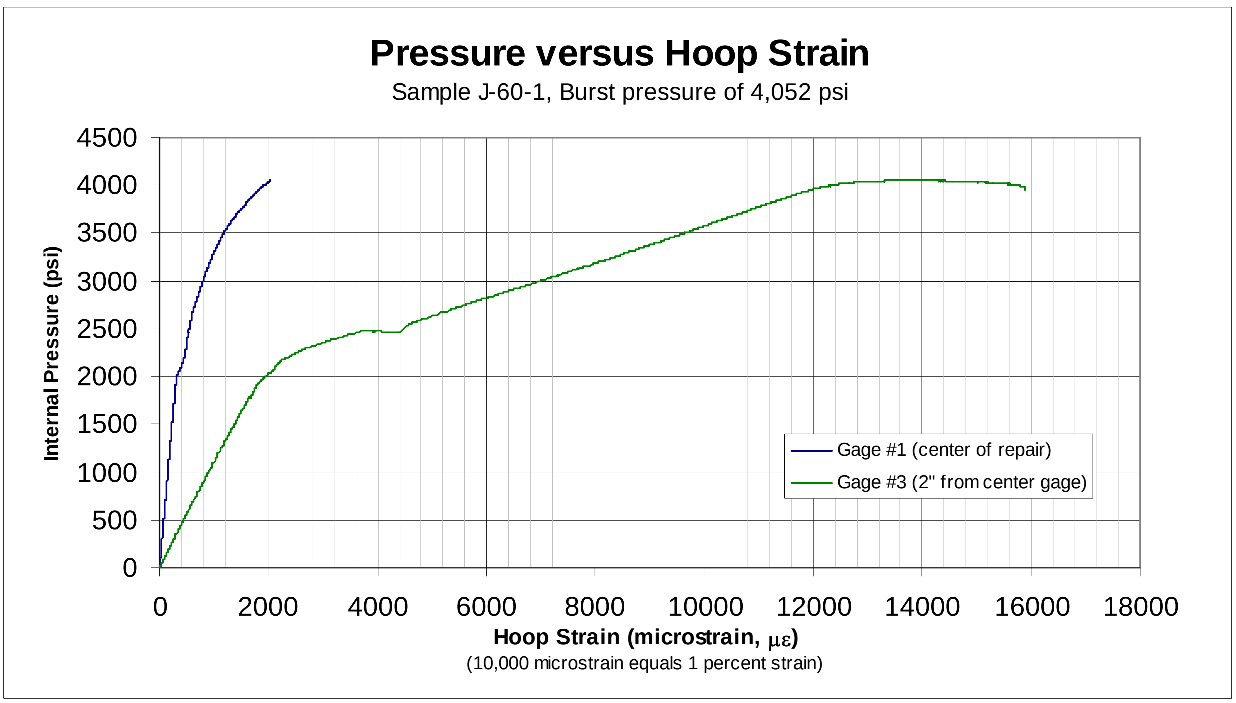


Figure 2 – Pressure vs. Hoop Strain, 60% Corrosion Sample

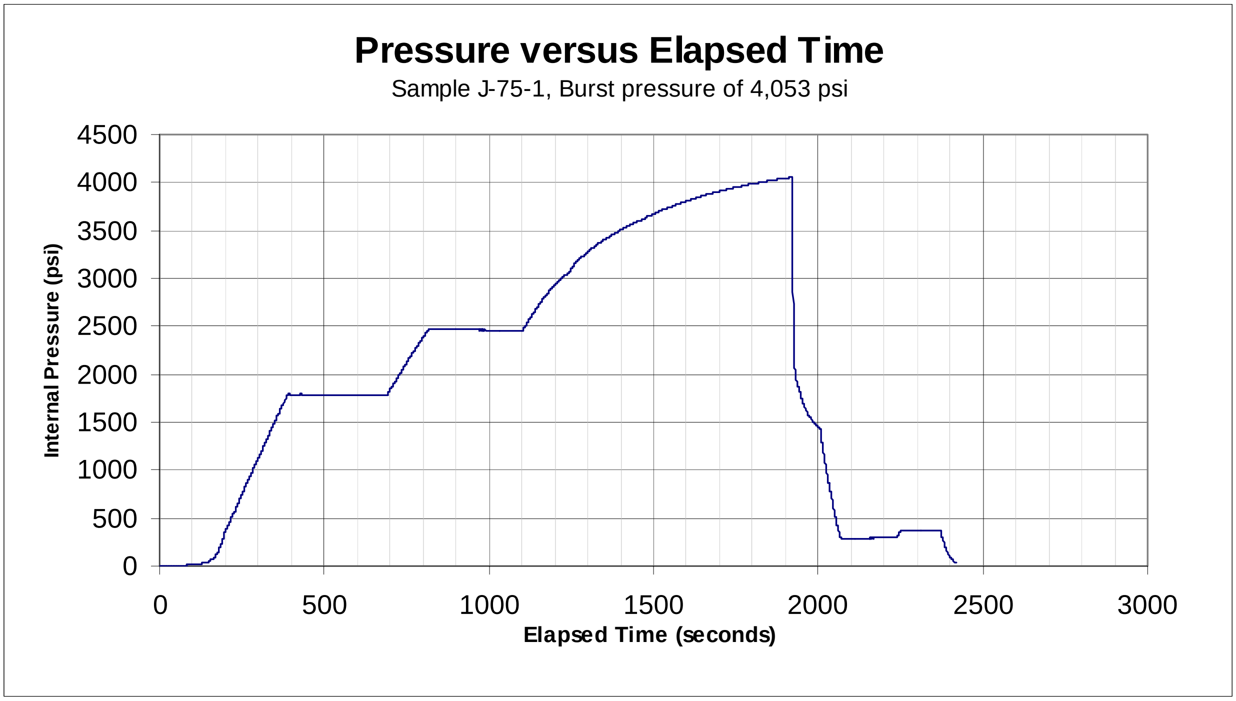


Figure 3 – Pressure vs. Elapsed Time, 75% Corrosion Sample

Figure 4 – Photograph of Failure Location, 40% Corrosion Sample

Figure 5 – Photograph of Failure Location, 60% Corrosion Sample

Figure 6 – Photograph of Failure Location, 75% Corrosion Sample

Specialized Tech Services

PO Box 355 Dobbin, Tx 77333
Phone - 713-515-3619

CALIBRATION CERTIFICATE

CUSTOMER: **MOHR Engineering Division**

13602 Westland East Blvd

Transducer Make:	Dynisco	Transducer Model:	G830-300-10M-K73
Transducer S/N:	190948939	Transducer Range:	0 - 10000 psi
Reference and testing conditions:		979.312 gals	24°C +/- 1.5 deg
		Excitation	5.0030 volts

CALIBRATION READINGS (as left)

ACTUAL (psi)	READING 1 (mv)	CONVERTED (psi)	PERCENT ERROR % of FS
0	0.044	0	0.00
500	0.788	496	-0.04
1000	1.537	996	-0.04
2000	3.034	1995	-0.05
4000	6.034	3997	-0.03
6000	9.036	5999	-0.01
8000	12.038	8002	0.02
10000	15.038	10004	0.04

All readings within manufacturer tolerence (+/- .5% F.S.)

CONVERSION FACTORS (Reading - Offset)*gain

Shunt Reading (millivolts)	Shunt Reading (psi)	Offset (millivolts)	Gain (psi/mv)
12.016	**7988**	0.044	667.20

Calibration performed per STS document PTC1001 and tracable to N.I.S.T.
Equipment used: Pressurements model M3800 SN:61205, Keithley 2000 Sn: 1068367

Technician L. Wilson DATE: April 23, 2010
SIGNED: RECALL: April 23, 2011

Figure 7 – Calibration Certificate for Pressure Transducer

Test Overview

Test Sample Configuration

The basic elements of this program include the following:

- Fabrication of 180 12.75-inch x 0.375-inch, Grade X42 8-ft long test samples with welded end caps (36 Year 0 burst tests and 144 buried samples).
- Sample preparation included simulated corrosion installed via machining with depths of 40%, 60%, and 75% of the pipe's nominal wall thickness (refer to Figure A for geometry of the machined regions).
- All samples were repaired by the participating manufacturers. All manufacturers repaired samples for a three-year test period (12 total samples), while four of the manufacturers elected to participate for a 10-year study (requiring an additional 9 samples).
- Burst tests were planned for all of the repaired samples at 0, 1, 2, and 3 years. The 10-year participants will have additional burst periods at 5, 7.5, and 10 years.
- While 36 samples were burst during the Year 0 test period, 144 samples were buried in the ground (cover depth of approximately 18 inches) at Stress Engineering's Waller, Texas Test Facility. Samples will be pressurized continuously at 36% SMYS (890 psi) and cycled 75 times per month at 36% SMYS (890 – 1,780 psi) and once per quarter at 72% SMYS (0 to 1,780 psi). Burst test samples will be removed from the buried trenches at the designated test periods and taken to failure.
- During the testing period, strain gages will be used to monitor strain in the corroded steel beneath the composite repairs. Figure B and Figure C provide a schematic of the strain gage locations and a photograph of the machined region with strain gages, respectively.

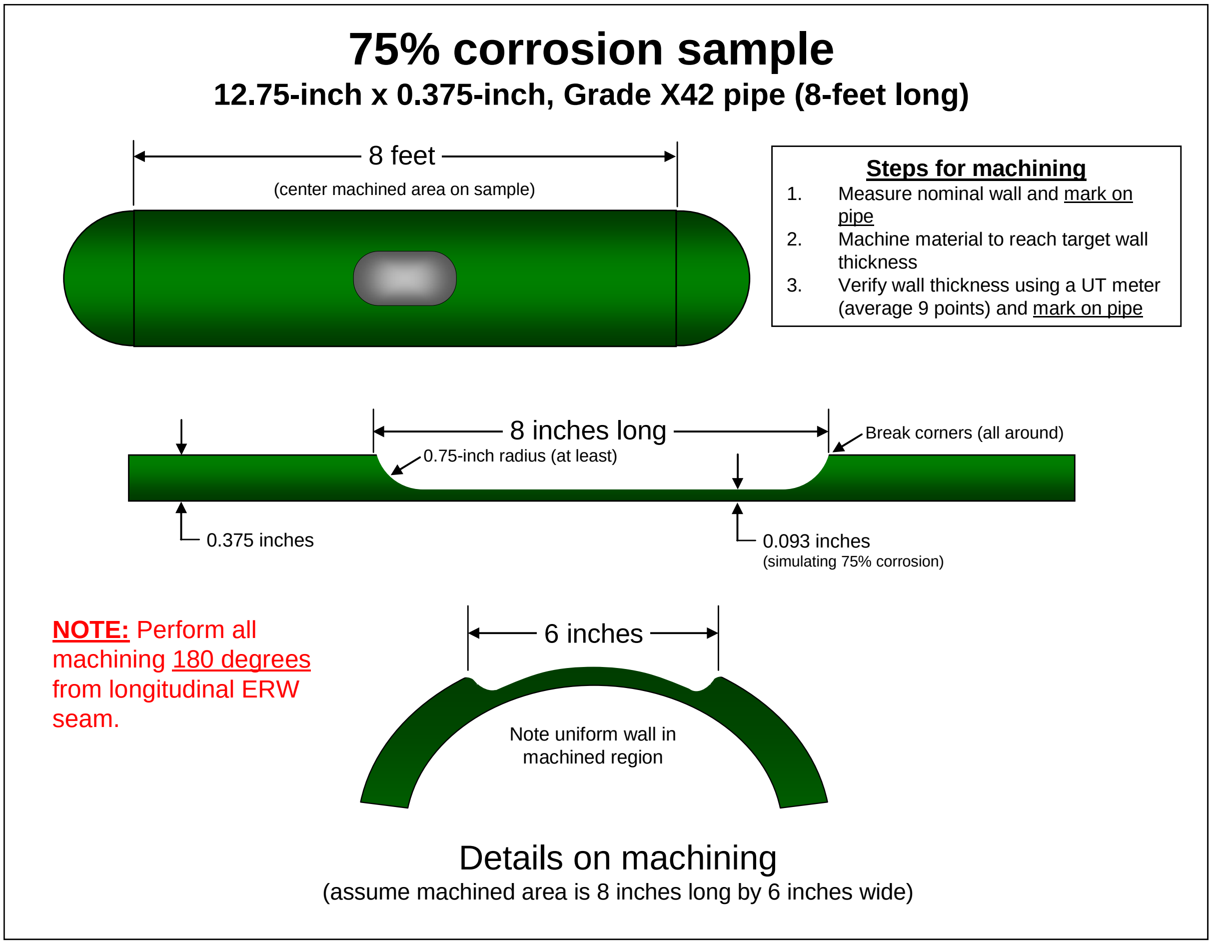


Figure A - Sketch of simulated corrosion

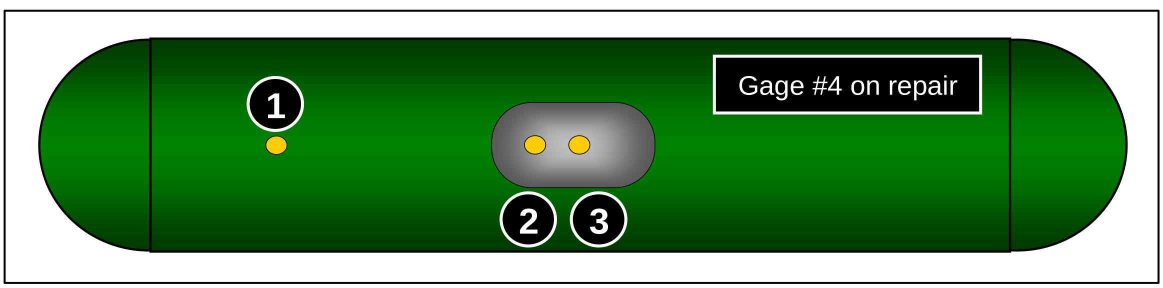


Figure B- Diagram of strain gage locations

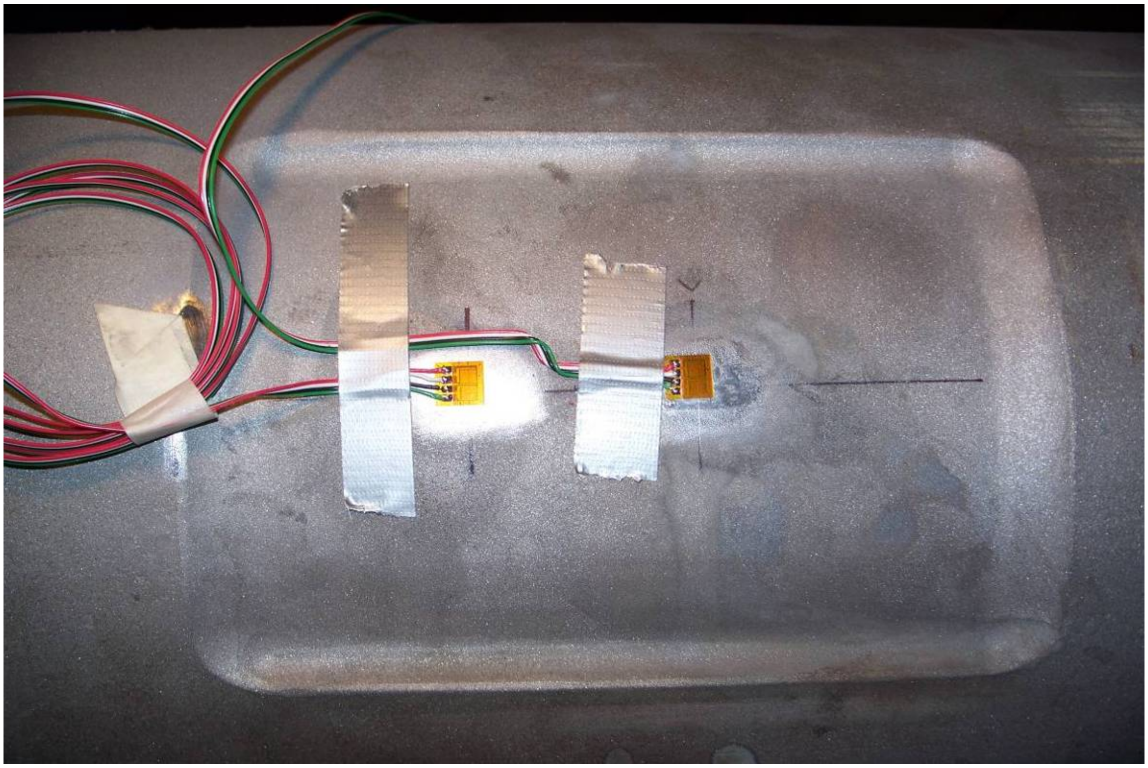


Figure C - Strain gages in simulated corrosion

Pipe Removal Activities

The 36 samples from the Year 1 group were unearthed prior to burst testing. Figure D provides photographs taken during the pipe removal activities.

Figure D - Photographs from Year 1 sample removal

W H LABORATORIES
8450 Rayson • Houston, Texas 77080 • 713/895-7504 • FAX 713/895-8906

Company:	Powerwrap, LP	Date:	07-16-2009
Attention:	Bill Vahrenkamp	Lab Report #:	09-0716-16
		P.O. #:	Verbal
Identification:	12 x 6 Carbon Panel		

TENSILE TEST

Lab ID	Dimensions	Area	Ultimate Load Lbs	Tensile P.S.I.	Fracture Location
1	.965 x .155	.1496	17,355	116,000	N/A
2	.950 x .173	.1643	17,349	105,600	N/A
3	.953 x .183	.1744	18,614	106,700	N/A
4	.997 x .172	.1715	16,130	94,100	N/A
5	.986 x .149	.1469	18,817	128,100	N/A
6	.943 x .182	.1716	15,741	91,700	N/A
7	.975 x .186	.1813	18,432	101,700	N/A
8	.948 x .173	.1640	15,851	97,300	N/A
9	.878 x .158	.1387	16,921	122,000	N/A

Tests performed in accordance with ASTM A370, E8, and WH Laboratories Quality Assurance Manual.
Test specimens retained for one (1) week maximum; unused material is retained for (1) month.

Approved by: Robert French
Robert French

EVALUATION OF THE AQUAWRAP™ SYSTEM IN REPAIRING MECHANICALLY-DAMAGED PIPES

PN114315CRA

Prepared for
AIR LOGISTICS, INC.
Azusa, California

September 2005
Revision 2

STRESS ENGINEERING SERVICES, INC.
Houston, Texas

EVALUATION OF THE AQUA WRAP™ SYSTEM IN REPAIRING MECHANICALLY-DAMAGED PIPES

PN114315CRA

Prepared for
AIR LOGISTICS CORPORATION
Azusa, California

Prepared by: ____________________
Chris Alexander

Reviewed by: ____________________
Daniel A. Pitts, P. E.

Stress Engineering Services, Inc.
13800 Westfair East Drive
Houston, Texas 77041

September 2005
Revision 2

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EXECUTIVE SUMMARY

Stress Engineering Services, Inc. performed a series of tests for Air Logistics, Inc. to evaluate the Aquawrap™ system for repairing mechanically-damaged pipelines. The purpose of the test program was to determine the benefits derived in repairing damaged pipelines subjected to cyclic pressure service using composite materials as well as grinding to remove gouges. Recognizing that third-party damage is the leading cause of pipeline failures in the United States, there is a significant need to have repair systems that can restore the serviceability of damaged pipelines.

The test program involved installing mechanical damage in the form of gouges and dents in two Grade X52 pipe sizes: 12.75-inch x 0.188-inch and 12.75-inch x 0.375-inch. Four 6-inch longitudinal gouges (depths of 15 percent of wall thickness) were installed in each of the 20-ft pipe samples using electric discharge machining (EDM). Dents were installed in each of these gouges with an initial depth of 15 percent of the pipe diameter (an elastic rebound occurs after the indenter is removed). Previous experience and research has shown that dents combined with gouges represent the most severe type of pipeline damage. After the dents were installed, the pipe samples were taken to 50 percent of the operating pressure which was selected as72% SMYS (specified minimum yield strength) to achieve a final residual dent depth. After pressurization a significant portion of the dent depth was removed (e.g. the dent depth for Sample AL-188-1 went from 5.0 percent before pressurization to a final dent depth of 2.3 percent after pressurization, while Sample AL-375-1 went from 7.8 percent before pressurization to a final dent depth of 5.2 percent after pressurization). This rerounding is expected, typical, and indicates that initial indentation levels may be severe even though a relatively shallow dent remains. After the dents were installed and pressurized according to the test procedure, the gouges were removed by grinding. This was done using a hand-held grinder and performed using gradual passes to ensure that too much of the pipe wall would not be removed. The dye penetrant inspection technique was used to ensure that the cracks at the base of the gouge were completely removed. On each of the two samples two of the dent/gouge defects were repaired by grinding, the other two were not. Of the two unground defects on each pipe sample, one was repaired using Aquawrap™ (making for a total of three composite repairs on each 20-ft long pipe sample). The intent of this repair was to see what level of reinforcement would be provided to unground dent/gouge defects.

Once the dents and gouges were removed, Aquawrap™ was installed over the appropriate damaged regions of the pipe samples. Installation was performed in accordance with the manufacturer's recommendations that specified the width and thickness of the repair. Once all of the repairs were made,

the materials were allowed to cure and pressure cycling was initiated. Testing involved cycling the samples to a pressure range equaling 100 percent of the maximum operating pressure. The test pipes were cycled until a failure occurred. When a failure did occur it was removed via cut-out and the remaining sections of the pipe re-welded so that pressure cycling could continue.

It is clear from the results of the test program that the reinforcement provided by Aquawrap™ provides an increase in the fatigue life of unrepaired mechanical damage. For the 12.75-inch x 0.188-inch pipe (D/t = 68) the fatigue life was increased from 103,712 cycles for the unrepaired sample, up to 928,736 cycles for the repaired sample (increase by a factor of 8.9). In a similar but more significant manner, the fatigue for the 12.75-inch x 0.375-inch pipe (D/t = 34) was increased from 2,272 cycles for the unrepaired sample up to 49,008 cycles for the repaired sample (increase by a factor of 21.6).

TESTING PROGRAM AND PROCEDURES

A specific test program was carried out on Aquawrap™. This program represents experience in testing and analyzing mechanically-damaged pipe spanning more than a 15-year period. The test program involves the two pipe sizes shown below. **Appendix A** contains documents associated with material testing (originally used to confirm the X52 grade). The purpose in selecting two pipes with different diameter to wall thickness ratios (D/t) is that the fatigue life of dented and mechanically-damaged pipes has been shown to be directly related to the pipe D/t ratio.

- 12.75-in x 0.188-in, Grade X52, diameter to wall thickness ratio of 68 (Sample AL-188)
- 12.75-in x 0.375-in, Grade X52, diameter to wall thickness ratio of 34 (Sample AL-375)

The test procedures for the cyclic pressure fatigue test are outlined below.

[1] Purchase pipes and install end caps that have been fitted with 1-inch weld-o-let bossets.

[2] Use EDM to create 6-inch longitudinally-oriented gouges that are 15 percent of the pipes nominal wall. The cross-sectional profile of the gouge is similar to a Charpy V-notch configuration with a **90° bevel and a 0.002-inch radius** at the base of the notch. Four (4) gouges were installed in each of the two (2) pipe samples, making for a total of eight (8) defects. The following gouge defects were made 90 degrees relative to the longitudinal pipe weld seam.

   a. Four (4) **6-inch long gouges, 0.028-inch deep** in the 12.75-in x 0.188-in pipe
   b. Four (4) **6-inch long gouges, 0.056-inch deep** in the 12.75-in x 0.375-in pipe

[3] Install dents in the pipe using a 6-inch wide plate. The initial indentation depth will be 15 percent of the pipes outer diameter and the indenter plate. Four dents will be installed in each 20-ft long pipe samples. Each dent will be offset 2 inches longitudinally from the respective gouge, resulting in a total defect length of 8 inches. **Figure 1** shows the dent installation rig.

[4] Allow each dent to reround elastically with removal of the indenter and measure the longitudinal profile (side view of dent and process shown in **Figure 2**).

[5] Apply internal pressure equal to 50 percent of the maximum operating pressure (36 percent of SMYS) and hold for 5 minutes. Return the internal pressure to 0 psi and measure the profile.

It should be noted that four (4) dent-gouge defects were installed in each pipe sample. Three (3) of these defects were repaired using the composite material and removal of the gouge by grinding; however, one defect was NOT repaired by grinding. The intent of the single defect was to serve as a baseline test case for unrepaired defects.

The following sequence of events was used in performing the repair of the defects:

[1] Remove the gouge by grinding with a hand-held grinder. Dye penetrant was used to ensure that the crack was completely removed. Measure the remaining wall thickness. **Figure 3** shows the application of dye penetrant to the damaged region and **Figure 4** shows one of the samples polished in its final state before installation of the repair material.

[2] Repair three of the four pipe defects using the composite reinforcement system. This includes the following activities:

    a. Prepare surface of pipe (for present short-term study, sandblasting not required)
    b. Fill in dented region of the pipe with a filler material to ensure proper load transfer for composite material from the carrier pipe.
    c. Install the composite material using the appropriate number of wraps.
        i. 12.75-in x 0.188-in pipe (thickness measured to be 0.830 inches)
        ii. 12.75-in x 0.375-in pipe (thickness measured to be 1.125 inches)
    d. Allow to cure in accordance with the manufacturer's recommendations.

[3] Start fatigue testing. Each sample was pressure cycled at 100% MAOP (72% SMYS or 100 to 1,200 psi for the 0.188-in wall pipe and 100 - 2,300 psi for the 0.375-in wall pipe) until failure occurs. As failures occur, the defects were cut out and removed to permit continued pressure cycling.

Figures 5 through **8** are photographs taken during the installation of Aquawrap™ on the damaged sections of the test pipes.

Figure 1 - Dent installation rig to install dents

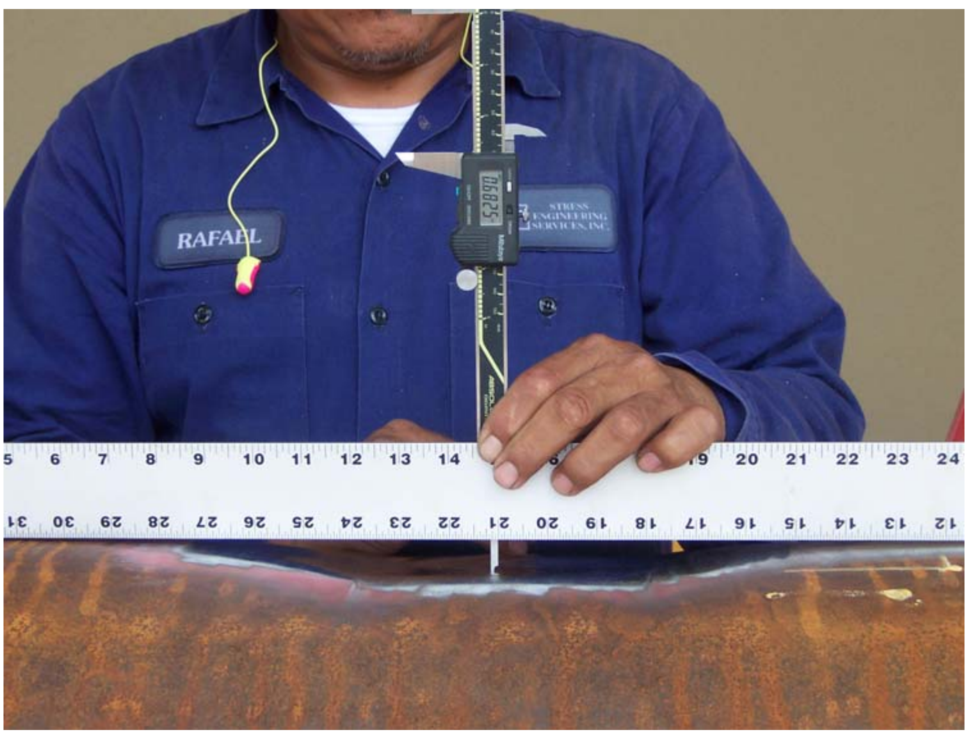


Figure 2 - Measuring dent depth and profile

Figure 3 - Dye penetrant used to ensure gouge removal by grinding

Figure 4 - Gouge removed by grinding

Figure 5 - Epoxy material used to fill the dented region

Figure 6 - First layer of Aquawrap™ installed on pipe

Figure 7 - Continued wrapping of Aquawrap™ in repairing damage

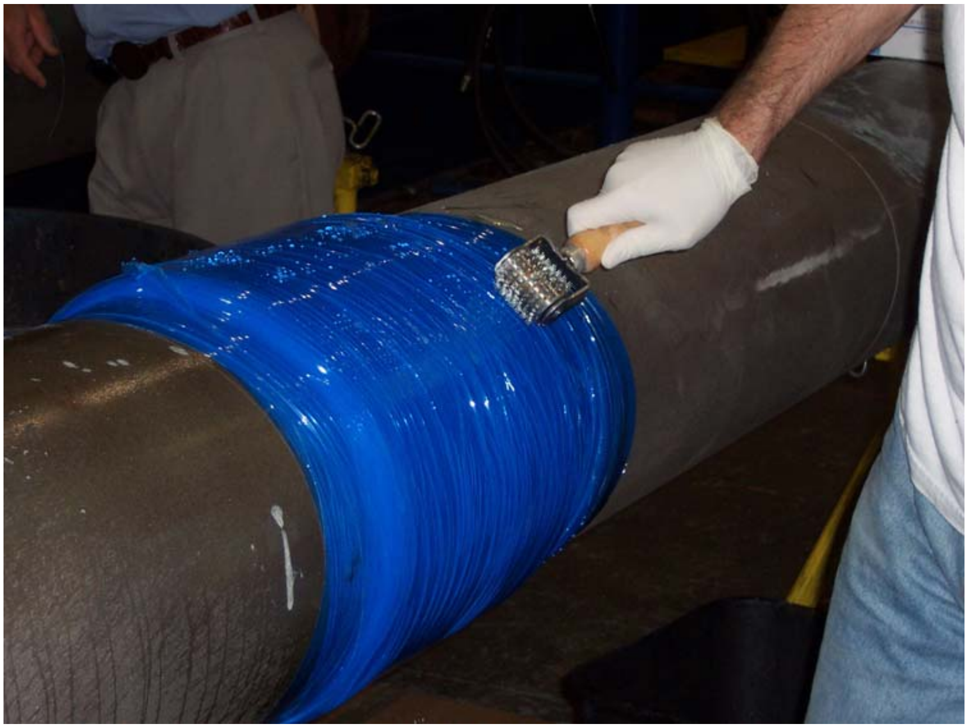


Figure 8 - Perforating plastic wrap to permit off-gassing during cure

RESULTS OF THE TEST PROGRAM

The results associated with implementation of the test program involve several important aspects. The first involves documentation of the dents themselves such as information on the force required to create the dents, dent depth, profile length, and response to internal pressure. This information is important as the ability to relate test data to actual field dents is directly related to the geometry of the dent. Additionally, it is important to document the test conditions and results associated with cyclic service. The conditions associated with the test pressure ranges are much more severe than most pipelines will experience in several lifetimes. For this reason it is important that the presentation help the reader make sense of the results as they relate to actual operating conditions of typical pipelines. The sections that follow provide details on these two areas of documentation.

Measurements Associated with Dent Geometry

There are several important parameters that were measured during the process of creating the test dents. These include:

- Dent depth as a function of test period (initial dent, rebound after indentation, and depth after pressurization)
- Dent profile measured along the length of the pipeline
- Force required to create the dents
- Pipe wall thickness before and after grinding

Table 1 provides a list of dent depth measurements taken during testing. Also included in this table are the average forces required to create the dents. As noted, the average force required to generate dents in the thicker-walled pipe is approximately 3.5 times the average force required to create dents in the thinner pipe having a nominal wall thickness of 0.188 inches. **Table 2** provides a list of measured wall thicknesses taken near the two defects in each sample that were repaired by grinding. Also included in this table are the percentages of remaining wall after grinding.

Figure 9 shows the longitudinal profile measurements for test samples AL-188-1 and AL-375-1. The measurements correspond to readings taken after initial indentation that capture the elastic rebound and measurements taken after pressurization to 50 percent MAOP. As with the data presented in **Table 1**, it is clear that a significant portion of the dent is removed by the application of internal pressure.

Table 1 - Sample dent depths

Sample Number	Target Dent Depth [(a)] (inches and percent O.D.)	Interim Dent Depth [(b)] (inches and percent O.D.)	Residual Dent Depth [(c)] (inches and percent O.D.)
12.75-inch x 0.188-inch, Grade X52 (D/t = 68) ***Average force of 26,010 lbs. required to generate dents***			
AL-188-1	1.9 (15%)	0.637 (5.0%)	0.293 (2.3%)
AL-188-2	1.9 (15%)	0.626 (4.9%)	0.290 (2.3%)
AL-188-3	1.9 (15%)	0.514 (4.0%)	0.240 (1.9%)
AL-188-4	1.9 (15%)	0.607 (4.8%)	0.272 (2.1%)
12.75-inch x 0.375-inch, Grade X52 (D/t = 34) ***Average force of 94,056 lbs. required to generate dents***			
AL-375-1	1.9 (15%)	1.001 (7.9%)	0.658 (5.2%)
AL-375-2	1.9 (15%)	1.020 (8.0%)	0.606 (4.8%)
AL-375-3	1.9 (15%)	1.001 (7.9%)	0.592 (4.6%)
AL-375-4	1.9 (15%)	1.028 (8.1%)	0.628 (4.9%)

Notes:
(a) *Target dent depth* is depth indenter initially pushed into pipe with no internal pressure
(b) *Interim dent depth* is the depth corresponding to elastic rebound as the indenter is removed from the pipe with no internal pressure.
(c) *Residual dent depth* is the depth remaining after the pipe sample was pressurized to 50 percent SMYS (760 psi for the 12.75-in x 0.188-in sample and 1,520 psi for the 12.75-in x 0.375-in sample)

Table 2- Wall thickness change of samples repaired by grinding

Sample Number	Nominal Wall Thickness (inches)	Measured Wall Base Pipe Thickness (inches)	Wall Thickness after Grinding (inches and percent nominal wall)
AL-188-3	0.188	0.198	0.168 (89.4%)
AL-188-4			0.158 (84.0%)
AL-375-3	0.375	0.385	0.314 (83.7%)
AL-375-4			0.306 (81.6%)

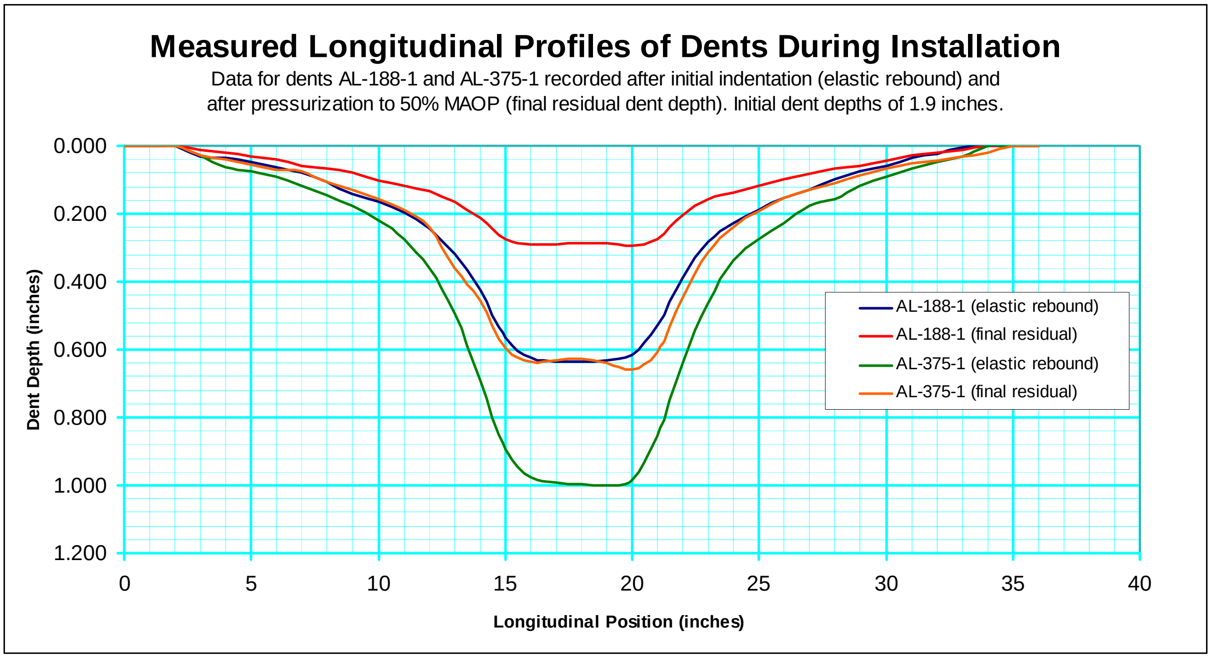


Figure 9 - Longitudinal profile measurements of exemplar dents

Fatigue Test Results

Fatigue testing applied a range of pressures equaling 100 percent of the MAOP (72% SMYS) to each pipe. The following pressure ranges were applied to the test samples:

- 12.75-in x 0.188-in, Grade X52: pressure range from 100 psi to 1,200 psi (1,100 psi MAOP)
- 12.75-in x 0.375-in, Grade X52: pressure range from 100 psi to 2,300 psi (2,200 psi MAOP)

Table 3 provides a summary of the fatigue test results including the cycles to failure for each of the 8 test samples. There are several noteworthy trends associated with the tabulated data.

- The cycles to failure for the unrepaired defects in the 12.75-inch x 0.188-inch pipe are unusually high. It is quite likely that the trend is due to the fact that the yield strength for this pipe was measured to be 69,700 psi. In this situation the applied stress range was insufficient to generate and grow the crack in a short period of time. The thicker wall pipe did not demonstrate this trend and showed a greater difference between the unrepaired and repaired samples.
- As expected, the pipe having the larger D/t ratio had a long fatigue life. This is consistent with the mechanics of the problem and previous research that show thinner wall pipes reround with internal pressure. As the effects of the dent are reduced, the fatigue life is increased.

- Although Aquawrap™ increased the fatigue life of the AL-188 sample, the effects of the repair were more pronounced with lower D/t pipe of the AL-375 sample.

In addition to the tabulated data, fatigue results are presented in **Figure 10** that plots cycles to failure for the Aquawrap™ samples as well as data from previous research programs associated with mechanical damage. The predominant observation made in viewing this figure are the benefits derived in repair by grinding and using composite materials as compared to unrepaired mechanical damage. If one considers a pipe having a D/t ratio of 50 with a dent of 15 percent and a gouge of 15 percent, the fatigue life can be estimated from **Figure 10** as follows.

- An unrepaired defect has an approximate fatigue life of 100 cycles
- A defect that has been repaired by grinding has an approximate fatigue life of 1,000 cycles
- A defect that has been repaired by grinding and fitted with an Aquawrap™ composite sleeve has an approximate fatigue life of 100,000 cycles

This trend is consistent in what has been observed with other composite repair systems. The primary reason for the increase in fatigue life is that the composite material restrains the dent and prevents significant rerounding during the process of pressure cycling. It is the flexure of the dent that is the basis for the initiation and propagation of fatigue cracks in both mechanically-damages pipes as well as pipes having plain dents (i.e. dents without gouges). Even though plain dents have fatigue lives that are significantly longer than pipes with mechanical damage (i.e. dents with gouges), the long-term failure of plain dents results from fatigue cracks that initiate in the dented region of the pipe.

Figures 11, **12**, **13**, and **14** show failures for samples AL-188-1, AL-118-2, AL-375-1, and AL-375-2, respectively. The key point to note is the radial deformation that occurs in the unrepaired defects (AL-188-1 and AL-375-1). The extensive deformation associated with the unrepaired defects confirms that the filler material must have a sufficient level of rigidity to prevent the radial deformation due to internal pressure.

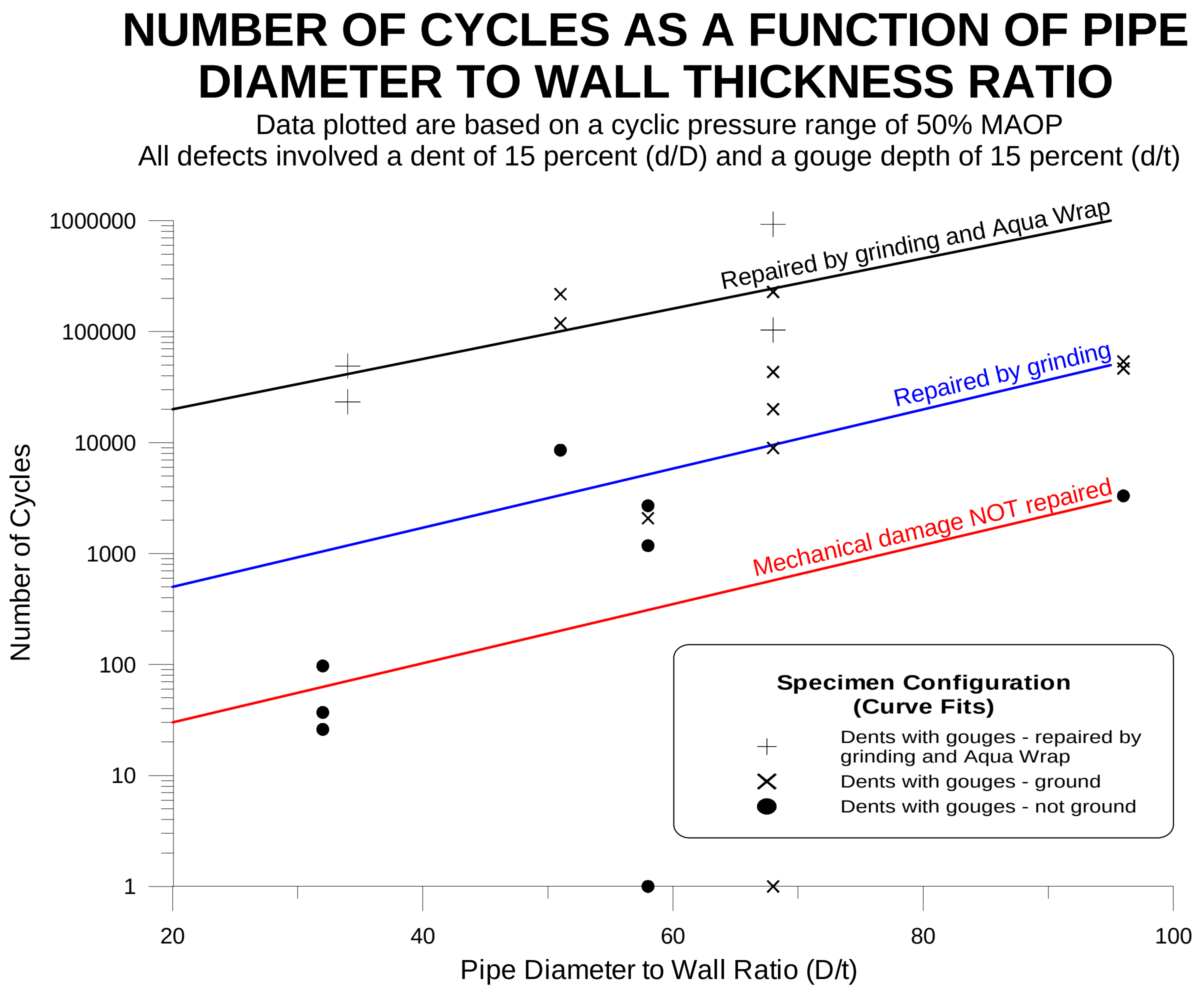


Figure 10 - Fatigue test results for mechanically-damaged samples

Figure 11 - Post-failure photo of Sample AL-188-1

Figure 12 - Post-failure photo of Sample AL-188-2

Figure 13 - Post-failure photo of Sample AL-375-1

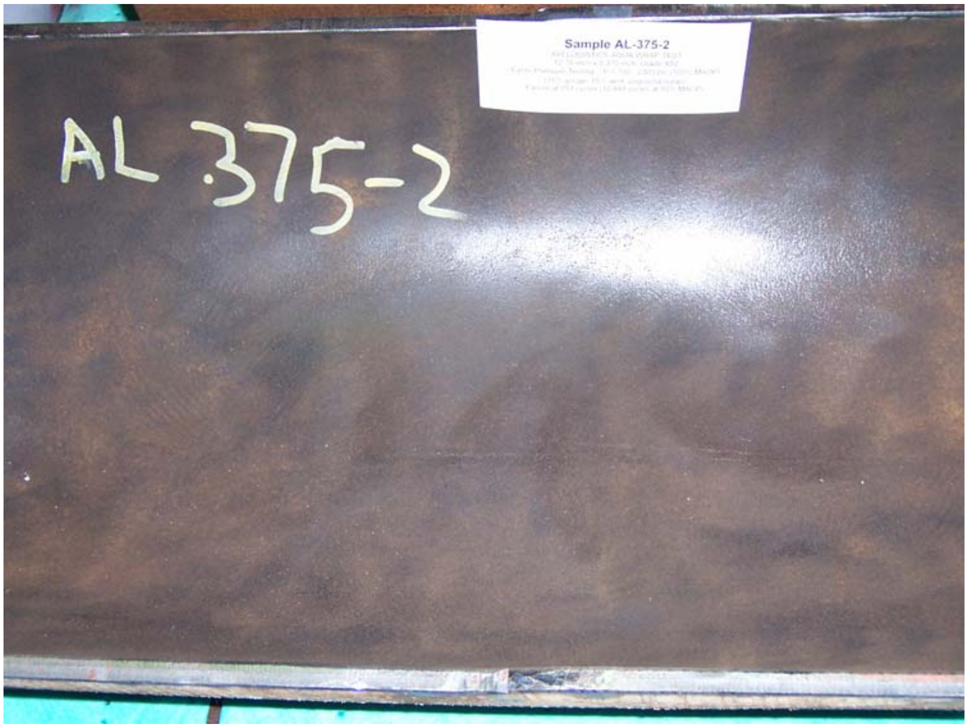


Figure 14 - Post-failure photo of Sample AL-375-2

Table 3 - Fatigue Test Results

Sample Number	Residual Dent Depth [(a)] (inches and percent O.D.)	Cycles to Failure at 50% MAOP [(b)] (100% MAOP)	Notes on sample
12.75-inch x 0.188-inch, Grade X52 (D/t = 68)			
AL-188-1	0.293 (2.3%)	103,712 (6,482)	Unrepaired
AL-188-2	0.290 (2.3%)	104,424 (6,544)	Aquawrap™, NO grinding
AL-188-3	0.240 (1.9%)	928,736 (58,046)	Aquawrap™, grinding [(c)]
AL-188-4	0.272 (2.1%)	103,536 (6,471)	Aquawrap™, grinding (pinhole leak developed under wrap, not found via inspection after testing)
12.75-inch x 0.375-inch, Grade X52 (D/t = 34)			
AL-375-1	0.658 (5.2%)	2,272 (142)	Unrepaired
AL-375-2	0.606 (4.8%)	10,448 (653)	Aquawrap™, NO grinding
AL-375-3	0.592 (4.6%)	23,296 (1,456)	Aquawrap™, grinding
AL-375-4	0.628 (4.9%)	49,008 (3,063)	Aquawrap™, grinding

Notes:
(a) *Residual dent depth* is the depth remaining after the pipe sample was pressurized to 50 percent SMYS (760 psi for the 12.75-in x 0.188-in sample and 1,520 psi for the 12.75-in x 0.375-in sample).
(b) Even though the samples were pressure cycled at 100% MAOP, it is possible to estimate the fatigue life at 50% MAOP using Miner's Rule and a fourth order relationship between stress range and cycles to failure.
(c) Grinding used to remove gouge before Aquawrap™ installed on pipe.

DISCUSSION OF RESULTS

In order for composites to be used on gas and transmission pipelines, pipeline operators will eventually require compliance with a recognized code or standard. Although the use of composites in repairing steel pipelines is widely-accepted among both gas and liquid operators, only recently have the ASME transmission pipeline codes recognized their use (B31.4 for liquid transmission pipelines and B31.8 for gas transmission pipelines). Additionally, in general the emphasis in using composite material has been on the repair of corrosion and not dents, gouges, or mechanical damage. This is expected as the greater potential for catastrophic failure in pipelines resides in the repair of mechanical damage as opposed to repairing corroded sections of pipe.

This section of the report has been prepared to address statements in the ASME B31.4 and B31.4 pipeline codes that relate to using composite materials to repair pipelines as well as comments related to repairing mechanical damage. To ensure clarity, an independent discussion on each of the two codes is provided.

ASME B31.4 - Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids

In terms of composite usage the following statement is made in ASME B31.4

451.6.2 Disposition of Defects

(c) Repair Methods

> *(14) Mechanically applied composite material wrap may be used to reinforce the pipeline provided that design and installation methods are proven for the intended service prior to application. The user is cautioned that a qualified written procedure performed by trained personnel is a requirement and records shall be retained…*

ASME B31.8 - Gas Transmission and Distribution Piping Systems

In terms of composite usage the following statement is made in ASME B31.8.

851.42 Permanent Field Repairs of Injurious Dents and Mechanical Damage

> *(e) Nonmetallic composite wrap repairs are not acceptable for the repair of injurious dents or mechanical damage, unless proven through reliable engineering tests and analysis.*

COMMENTS AND CLOSURE

This report has provided documentation on a test program performed by Stress Engineering Services, Inc. for Air Logistics on the Aquawrap™ composite repair system for high pressure pipelines. Aquawrap™ is a water-activated pre-impregnated (i.e. prepreg) composite system that is installed directly over areas of pipeline damage. The focus of the test program carried out by SES was to address the ability of Aquawrap™ to repair mechanically-damaged pipes involving dents with gouges. The test program involved full-scale testing involving two Grade X52 pipe sizes: 12.75-inch x 0.188-inch and 12.75-inch x 0.375-inch. Four 6-inch long gouges (depths of 15 percent of wall thickness) were installed in each of the 20-ft pipe samples using EDM. Dents were installed in each of these gouges with an initial depth of 15 percent of the pipe diameter (an elastic rebound occurs after the indenter is removed). After the dents were installed, the pipes were pressurized to 50% MAOP to achieve a final residual dent depth. Finally, select gouges were removed by grinding and repairs were made using Aquawrap™. Once all of the repairs were made, the materials were allowed to cure and pressure cycling was initiated. Testing involved cycling the samples to a pressure range equaling 100 percent of the maximum operating pressure. The test pipes were cycled until a failure occurred. When a failure did occur it was removed (cut-out) and the remaining sections of the pipe re-welded so that pressure cycling could continue.

It is clear from the results of the test program that the reinforcement provided by Aquawrap™ provides an increase in the fatigue life of unrepaired mechanical damage. For the 12.75-inch x 0.188-inch pipe (D/t = 68) the fatigue life was increased from 103,712 cycles for the unrepaired sample, up to 928,736 cycles for the repaired sample (increase by a factor of 8.95). In a similar but more significant manner, the fatigue for the 12.75-inch x 0.375-inch pipe (D/t = 34) was increased from 2,272 cycles for the unrepaired sample to 49,008 cycles for the repaired sample (increase by a factor of 21.6).

When Aquawrap™ is properly used to repair damaged pipeline, including the removal of shallow gouge defects by grinding, it is possible that a significant increase in fatigue life can be achieved over unrepaired defects. The results of this test program, along with supporting data from similar repair system, confirm the validity of this repair system. It should be noted, however, that significant care should be taken in repairing actual mechanically-damaged pipelines. Consideration of period service history, material quality, and extent of overall pipeline damage must be considered before making a pipeline repair using composite materials.

APPENDIX A - Material Test Reports

Houston Metallurgical Laboratory Inc.

2400 Central Parkway, Suite R
Houston, TX 77092-7712
Phone: (713) 688-2777
Fax: (713) 688-2818
Email: houmet@swbell.net

TO: Stress Engineering Services
13800 Westfair East Drive
Houston, Texas 77041
Attn: Chris Alexander

TEST NO: 795-05
P. O. NO:
DATE: 6-7-05

DATE OF TEST: 6-7-05

REPORT OF TENSILE AND CHARPY TEST

MATERIAL / DESCRIPTION: One (1) piece 12" OD x .188" wall API 5L Gr. X52 Pipe
IDENTIFICATION: P/N 114315 CRA
DATE RECEIVED: 6-6-05
SPECIFICATIONS: Client instructions
TEST EQUIPMENT: T.O. 120990-1 Ext. CL5284
Tinius Olsen Model 74:264 Ft./Lb. 16.8 Ft./Sec. S/N 121155
Temp.. Monitor: S/N C-111 Temp. Controller: S/N 194047049

TECHNICIAN: M. Steel / D. Chalmers
PROCEDURE: HML-TTM-1-94 Rev. 1
HML-CVN-1-94 Rev. 1
COMPLIANCE:

TENSILE TEST RESULTS

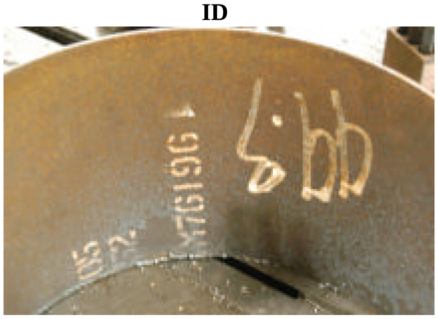
SPECIMEN NO:	DIMENSIONS	SQ. AREA INCH	YIELD STRENGTH PSI .2% OFFSET	TENSILE STRENGTH PSI	% ELONG. IN 2 IN.	% ROA
795-05	1.505 x .184	.2769	69,700	78,900	31.25	48.2

CHARPY IMPACT TEST RESULTS

ASTM E23 TYPE: a SIZE: 10mm x 2.5mm

SPECIMEN NO:	TEST TEMP.	NOTCH LOCATION	FT. LBS.	% SHEAR	LAT. EXP (MILS)
795-05 (Transverse)					
#1	Ambient	Base	19	99	55
#2	"	"	18	99	52
#3	"	"	18	99	51
#1	+32 degrees F	Base	18	99	54
#2	"	"	18	99	53
#3	"	"	18	99	53

ID



AFTER MAPPING

AFTER MACHINING

REVIEWED BY:

RONALD RICHTER
PRINCIPAL / QA MANAGER

Houston Metallurgical Laboratory Inc.

2400 Central Parkway, Suite R
Houston, TX 77092-7712
Phone: (713) 688-2777
Fax: (713) 688-2818
Email: houmet@swbell.net

TO: Stress Engineering Services
13800 Westfair East Drive
Houston, Texas 77041
Attn: Chris Alexander

TEST NO: 796-05
P. O. NO:
DATE: 6-7-05

DATE OF TEST: 6-7-05

REPORT OF TENSILE AND CHARPY TEST

MATERIAL / DESCRIPTION: One (1) piece 12" OD x .375" wall API 5L Gr. X52 Pipe
IDENTIFICATION: P/N 114315 CRA
DATE RECEIVED: 6-6-05
SPECIFICATIONS: Client instructions
TEST EQUIPMENT: T.O. 120990-1 Ext. CL5284
Tinius Olsen Model 74:264 Ft./Lb. 16.8 Ft./Sec. S/N 121155
Temp.. Monitor: S/N C-111 Temp. Controller: S/N 194047049

TECHNICIAN: M. Steel / D. Chalmers
PROCEDURE: HML-TTM-1-94 Rev. 1
HML-CVN-1-94 Rev. 1
COMPLIANCE:

TENSILE TEST RESULTS

SPECIMEN NO:	DIMENSIONS	SQ. AREA INCH	YIELD STRENGTH PSI .2% OFFSET	TENSILE STRENGTH PSI	% ELONG. IN 2 IN.	% ROA
796-05	1.501 x .369	.5539	66,100	73,100	39.85	63.6

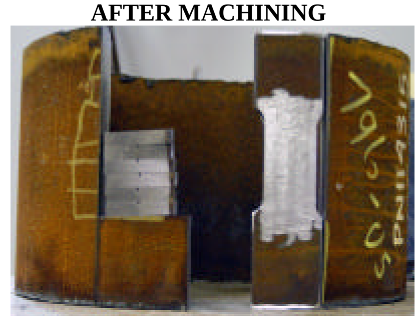
CHARPY IMPACT TEST RESULTS
ASTM E23 TYPE: a SIZE: 10mm x 7.5mm

SPECIMEN NO:	TEST TEMP.	NOTCH LOCATION	FT. LBS.	% SHEAR	LAT. EXP (MILS)
796-05 (Transverse)					
#1	Ambient	Base	54	99	65
#2	"	"	50	99	64
#3	"	"	50	99	63
#1	+32 degrees F	Base	37	99	51
#2	"	"	36	99	47
#3	"	"	30	99	42

ID

AFTER MAPPING

AFTER MACHINING



REVIEWED BY:

RONALD RICHTER
PRINCIPAL / QA MANAGER

Analysis of Aquawrap® for use in Repairing Damaged Pipelines

Environmental Exposure Conditions
Property Testing Procedures
Field Testing Evaluations

Prepared By
Franz L. Worth, PE

January 7, 2005

Air Logistics Corporation
F.A.C.S.™ Group
925 North Todd Avenue
Azusa, CA 91702 USA
Phone 626-633-0294 • Fax 626-633-0791

INTRODUCTION

The repair of corroded or damaged pipelines using composite repair systems is growing, especially in the oil and gas industries. Composites have proved themselves as a strong and durable material, capable of providing the qualities required when performing critical repairs. Numerous field trials, in-house testing, and third party testing has demonstrated that **Aquawrap®** possesses those performance qualities, and as such, has been successfully used on many pipelines for repairing external corrosion and mechanical damage.

Aquawrap® is comprised of a proprietary polyurethane formula and custom-woven biaxial glass fiber. As a biaxial fabric, it provides strength in two directions, hoop and transverse. For piping, hoop strength is critical, but handling the transverse load is also important. Strength in two directions can be equally important to many other types of reinforcement that **Aquawrap®** is designed to handle. For these reasons, biaxial fabric was a sound choice.

The material installation requires use of a base primer material to provide a proper bond to the surface being repaired. **Aquawrap®** is then installed, utilizing water as the activator. The material can be installed circumferentially around the object, or spiraled at an angle to provide uniform coverage over long distances. After installation, a unique method is used to compress and consolidate the composite.

The purpose of this analysis is to provide a single document, which summarizes the entire properties test results and field testing results. The following is an analysis of tests and trials completed that relate to repairing pipelines, as well as other cylindrical objects of metal or concrete. The results will reveal that these tests prove **Aquawrap®** is a practical and economical repair for damage to these structures, and in many cases, can increase the strength and durability of the virgin object.

F.A.C.S.™ GROUP QUALITY OVERVIEW

Objective

To produce a high quality product having outstanding performance characteristics with consistent handling and mechanical properties coupled with excellent longevity. The program, from product design through field performance monitoring, is outlined below.

Design

The design activity entails not only that of the product but of the facility and equipment required to produce it.

Product Design: The product design activity required several years of resin development and testing coupled with evaluation of fabric weaves and construction alternates. The design activity has produced a number of product variants to suit specific customer applications.

Facility and Equipment: Due to the water cure nature of the product, consideration must be given to the facility design and construction. The facility must be designed to maintain a low ambient humidity and temperature control in spite of the effects of material and personnel entry and egress. The equipment required to produce the product entails measuring and mixing of the various resin formulations, drying the fabric, impregnation of the fabric, and product packaging. Air Logistics has completed the design, fabrication and construction of a well-equipped facility for the Manufacturer of its Aquawrap products.

Development and Qualification Testing

Air Logistics has completed extensive strength and environmental testing as a part of the product development process utilizing our internal test facility. Outside test laboratories have confirmed the results of this internal testing. Having complete test capability is a key asset in the product formulation and the ongoing product improvement process.

Workmanship Practices

The development of, and rigorous adherence to, proper workmanship and processing practices is essential to achieve quality manufacturing of a unique product such as **Aquawrap®**. Air Logistics has developed a complete set of operational processes and procedures for the manufacture of its products. These processes include, but are not limited to, incoming material inspection, resin mixing, facility environment monitoring, equipment set-up, operational functions, and packaging integrity.

Incoming Material: Supplier certifications are required on all incoming production material used in the manufacturing process. The certifications are maintained as a part of the quality records. Where appropriate, physical measurements of testing are completed and recorded.

Material Traceability: Lot numbers of all materials used in production are recorded. Retains are also kept for future inspection if needed. Resin mixing and daily run MO logs are used to record traceability data for all components used in the production of each lot of **Aquawrap®** material. In addition, equipment setup settings are also logged.

Packaging: Packaging quality is essential to the production process due to the moisture cure nature of **Aquawrap®**. If the packaging material is faulty or if the pouch seal is improperly finished, the material will cure before it can be used in the field. Close attention to the sealing machine setup and operation is crucial. Each pouch is inspected as it is labeled for shipment to assure that the pouch and its seal are intact.

Product Testing: As part of our commitment to quality assurance, samples from different lots of product are periodically drawn from production, made into coupons, and tested.

Field Evaluation: Material quality data are collected and monitored as received from users. Should problems develop, they will be investigated to isolate the root cause and corrective actions will be taken as required.

Test Facilities

Air Logistics has a test facility capable of verifying most of the mechanical and life characteristics of our **Aquawrap®** products. Each test complies with the appropriate ASTM standard and procedure. When a required test is beyond the scope of our facility, the material is sent to a reputable third-party test lab. The ability to test and verify new and existing products is key in the development process, as well as ongoing quality assessments.

TEST DESCRIPTIONS

This section details the various property tests Air Logistics Corporation has completed on its **Aquawrap®** material. Results of the test are provided. As mentioned, testing has been conducted in a multitude of venues. Each test indicates the location of the test facility. All of the testing, as well as the results, have been reviewed and approved by Air Logistics' quality control department.

Those tests that were done by an independent group have been referenced here. The results indicated by those tests have been reviewed by Air Logistics Corporation, and found to be consistent with its own private and third party tests.

2.0 Individual Tests Performed

Tests 2.1 through 2.7, 2.9, 2.10, 2.16, 2.24 and 2.25 were performed on the current **Aquawrap®** product. The balance of the tests have been conducted over the past two years and used a number of different fabric weaves and weights which produced lower and sometimes higher tensile and other properties. Unless otherwise noted, the resin system in all of the tests is the same and, as such, the comparative results remain valid.

2.1 Tension -
The tensile properties of the material are determined in accordance with ASTM D-3039. The data includes not only the tensile characteristics of the material but modulus and strength per ply data as well.

2.2 Flexural Strength -
The flexural properties of the product were determined by testing in accordance with ASTM 790. The data includes both the flexural strength and modulus.

2.3 Compressive Strength -
The compressive properties of the product were determined by testing in accordance with ASTM D-695.

2.4 **Interlaminar Shear** -
The interlaminar shear strength of the product was determined by the short beam shear method in accordance with ASTM D-2344.

2.5 Tg -
The Tg of the material was determined in accordance with ASTM D-831.

2.6 Flammability -
The flammability of the product was determined by testing in accordance with ASTM E-84.

2.7 **Burst Strength** -
The burst strength of the product was determined by testing cured NOL rings on a burst fixture. The results were converted into strength per ply and compared to tensile strength determined in paragraph 2.1 above.

2.8 **Tension Properties of the product cured under water** -
This test was done in order to determine if the tensile properties are affected when **Aquawrap®** is cured under water. This test duplicates any situation where the material is applied under water such as on a pier piling or pipeline. The test consists of preparing and curing a panel under water and then tension testing it in accordance with ASTM D-3039. In this case the important parameter is the strength per ply, as the compression of the lay-up completed under water is not as good as a normally prepared laboratory sample.

2.9 **Adhesion (Lap Shear) to Steel, Stainless Steel and Aluminum** -
Although a specific ASTM test does not exist, ASTM D-3165 was used as a guide. The test consisted of bonding three one-inch wide pieces of the product to one-inch wide A36 steel, 304 stainless steel, and 6061 aluminum strips with various surface preparations and Base Primer No.1 adhesive. The cured samples were then tension tested to determine the shear force required to break the bond between the three layers of cured product and the stainless steel or aluminum.

2.10 Thermal Cycling of Aluminum Bonded Joints -
This test is on joints similar to those in paragraph 2.9 which have been subjected to thermal cycling. Samples of the product bonded to aluminum as in paragraph 2.9 above and subjected to a total of thirty freeze thaw cycles from 0°F to 70°F. After each cycle the coupons were removed from the freezer and placed in water at 70°F and placed back in the freezer wet. The coupons were allowed to stabilize for a period of at least one-hour. At the end of the test the bond strength of the samples were determined and compared to unexposed samples.

2.11 Alkali Soak -
Panels of the cured product are placed in a closed tank filled with water at a pH level of 9.5 for a period of 3000 hours. At the completion of the 3000-hour soak the panels are removed, dried off, weighed, cut into coupons, and tension tested in accordance with ASTM D-3039. The results are then compared to coupons made from the same material.

2.12 Salt Water Soak -
This test is identical to the alkali soak test above except that the panels are soaked in seawater rather than an alkali solution. The duration of this test is 10,000 hours.

2.13 Tensile Properties at Elevated Temperatures -
See sections 2.21 and 3.21 for details of the testing and the results. These sections provide data on creep testing, which is then related to tensile strength.

2.14 Cure Time -
This test is intended to determine the cure time of thick lay-ups of the product. Several panels of the product were prepared and cured. They were then cut into coupons for interlaminar shear testing over a 24-hour period. The coupons were tested in accordance with ASTM D-2344 immediately after they were cut. The data was then analyzed to determine the cure time of the resin in these thick samples.

2.15 Cathodic Disbondment -
The cathodic disbonding properties of the product were determined in accordance with ASTM G-8.

2.16 **Chemical Resistance** -
The chemical resistance of the product to various liquids was determined in accordance with ASTM D-831(A).

2.17 Impact Resistance -
Impact resistance of cured material was determined by testing in accordance with ASTM D-5420-98a, “Standard Test Method for Impact Resistance of Flat, Ridged Plastic Specimen by Means of a Striker Impacted by a Falling Weight (Gardner Impact)”. The panels were fabricated

using three layers of woven roving (G-05) and one layer of tape (G-03).

2.18 UV Resistance -
A cured panel of colored UV resistant material was placed in a chamber simulating the conditions of ASTM D-2565 for a period of five weeks. After the exposure the panel was visually examined and cut into coupons. The coupons were then tension tested in accordance with ASTM D-3039 and the results compared to unexposed coupons.

2.19 Long Term Exposure to Dry Heat -
Two panels of slightly different construction were placed in dry heat at 140°F for periods of 1000 and 3000 hours. At the end of each exposure the panels were visually examined, weighed, cut into coupons, and tension tested in accordance with ASTM D-3039. The results were then compared to unexposed coupons.

2.20 Diesel Soak -
This test is identical to the Alkali Soak test above except that the panels are soaked in diesel rather than an alkali solution. The duration of this test is 2,000 hours.

2.21 **Creep Rupture Tests** -
Coupons were loaded in tension on a specially designed load frame, which maintains a constant tensile force on the coupons. The basis for this test is ASTM's D-2990 and D-2992. The intent of the test is to determine the long-term tensile performance of the composite material by establishing a load profile and extrapolating it on a semi-logarithmic scale. These tests were conducted at the University of Wyoming.

2.22 Cyclic Loading -
ASTM D-3039 type coupons were subjected to repetitive loads (sine wave) in a conventional load frame. Coupons were tested over a range of peak loads until they failed. The load vs. cycles to failure was then recorded and plotted on a semi-logarithmic scale.

2.23 NSF Approval -
NSF International tested and approved **Aquawrap®** under its guidelines for NSF Standard 61.

3.0 Summary of Test Results

3.1 Tension: The tension test results are summarized in the following table:

3.1 TENSION PROPERTIES	THICKNESS (inches)	AREA SQUARE (inches)	ULTIMATE LOAD (pounds)	TENSILE STRENGTH (psi)	TENSILE MODULUS (e^6 psi)	STRENGTH PER INCH PER PLY (pounds)
AVERAGE RESULTS	0.056	0.057	3,921	68,983	3.74	769

Test number 1691. The standard deviation of the tensile strength of the samples is 3,140 PSI, or about 4.6% of the average tensile and is an indication of a good test. **Location L1.**

3.2 Flexural Strength: The results of the testing are as follows:

3.2 FLEXURAL STRENGTH PROPERTIES	WIDTH (inches)	THICKNESS (inches)	SPAN (inches)	ULTIMATE LOAD (pounds)	FLEXURAL STRENGTH (psi)	FLEXURAL MODULUS (e^6 psi)
AVERAGE RESULTS	1.033	0.107	2.00	167	42,368	2.968

Test number 1773. **Location L1.**

3.3 Compressive Strength: The results of the testing are as follows:

3.3 COMPRESSIVE STRENGTH PROPERTIES	THICKNESS (inches)	WIDTH (inches)	ULTIMATE LOAD (pounds)	COMPRESSIVE STRENGTH (psi)	COMPRESSIVE MODULUS (e^6 psi)	COMPRESSIVE STRENGTH PER INCH PER PLY (pounds)
AVERAGE RESULTS	0.3293	0.5114	4,715	28,066	4.00	369

Test numbers are 1775 and 1776. The results of these tests are averaged. **Location L1.**

3.4 **Interlaminar Shear:** The results of the tests are as follows:

3.5 INTERLAMINAR SHEAR	WIDTH (inches)	THICKNESS (inches)	SPAN (inches)	ULTIMATE LOAD (pounds)	INTERLAMINAR STRENGTH (psi)
AVERAGE RESULTS	1.021	.247	1.00	1,134	3,372

Test number 3485. **Location L1.**

3.5 Tg: Test number T-36462-131794. The Tg of the sample was 142°C (288°F). **Location L3.**

3.6 Flammability: Test number 162244. The flame spread was 110 and the smoke density was 385. This certifies the material to NFPA Class C or UBC Class III. **Location L5.**

3.7 **Burst Strength:** The results of the burst strength testing are as follows:

3.7 BURST STRENGTH			
SAMPLE	PRESSURE (psi)	PLIES	STRENGTH PER PLY PER INCH OF WIDTH (pounds)
BASELINE			800
1	1,434	17	844
2	1,390	17	818
3	1,372	17	807
4	1,425	17	838
AVERAGE	1,405	17	823

In all cases the samples failed at loads above the baseline. This is partially due to the fact that the test duration is a bit shorter than ASTM D-3039 coupon test. Excellent results are still observed. **Location L2.**

3.8 **Tension Properties of the product cured under water:** This test was performed on a 24 oz. unidirectional material. The average tensile properties of material cured under water and cured per the field lay-up procedure are as follows:

3.8 TENSION PROPERTIES	THICKNESS (inches)	AREA SQUARE (inches)	ULTIMATE LOAD (pounds)	TENSILE STRENGTH (psi)	TENSILE MODULUS (e^6 psi)	STRENGTH PER INCH PER PLY (pounds)
FIELD PROCEDURE CONTROL	0.0772	0.0771	4,583	59,580	3.58	2,294
FIELD SAMPLE	----	0.0801	4,582	57,180	---	2,287
UNDER WATER LAY-UP	0.0849	0.0868	4,511	52,136	3.36	2,207
ADJUSTED UNDER WATER LAY-UP	0.0770	0.0790	4,511	57,553	3.71	2,207
VACUUM LAY-UP	0.0568	0.0565	4,686	83,160	5.08	2,354

Test numbers are 833, 578, 1661 and 226. The key data in this test is the strength per ply, which are comparable within the expected deviation between the two tests. The compression of the sample cured under water was not as respectable as the control panel, resulting in a thicker panel. If the thickness of the test panel is adjusted to be the same as the control panel, the tensile strength and modulus are comparable to those of the control panel. The Shore D hardness of the panel cured under water was 85, which is typical of a normal vacuum lay-up. **Location L1.**

3.9 **Adhesion to Steel, Stainless Steel, and Aluminum:** The test was performed on steel and aluminum with four configurations using Base Primer No. 1 adhesive. The results of the test are as follows:

3.9 SUBSTRATE	NO ADHESIVE NO ABRASION (psi)	ABRASION NO ADHESIVE (psi)	ADHESIVE NO ABRASION (psi)	ADHESIVE ABRASION (psi)
STEEL	NO TEST	NO TEST	NO TEST	910
STAINLESS STEEL	602	717	1,008	1,128
ALUMINUM	557	604	557	1,009

Test numbers are 1130, 1132, 1133, 1135, 1824 and 3342. The area of the bond in each test was one inch and the units of the pull off strength are both pounds and PSI. **Location L1.**

3.10 Thermal Cycling of Aluminum Bonded Joints: The results of the tests are as follows:

3.10 BONDING TO ALUMINUM	AVERAGE PULL OFF STRESS (psi)
BASELINE	870
CYCLED - NO ALODINE	537
CYCLED - WITH ALODINE	965

Test numbers are 2957 and 3008. The bond does not appear to be affected by the freeze thaw cycling, in fact the strength increased during the cycling. The use of Alodine is important as the bond strength increased dramatically by its use. This is true in pull off tests without freeze thaw cycling as well. **Location L1.**

3.11 Alkali Soak: The tensile strength of the processed panels and reference panels are as follows:

3.11 TENSION	THICKNESS (inches)	AREA SQUARE (inches)	ULTIMATE LOAD (pounds)	TENSILE STRENGTH (psi)	TENSILE MODULUS (e^6 psi)	STRENGTH PER INCH PER PLY (pounds)
BASELINE RESULTS	0.043	0.044	1,860	42,743	3.02	366
AVERAGE RESULTS	0.035	0.035	1,576	44,827	2.50	315

Test numbers 1753 and 1223. The weight of the coupon at the start of the test was 107.7 grams. The weight at the end of the test was 107.6 grams. The Shore D at the end of the test was 85. There is no change in the appearance of the coupon. The difference between the baseline and processed data are within the normally expected deviation and the conclusion is that the processing had no affect on the material. However, for some reason the modulus of the processed panel appears to be low. **Location L1.**

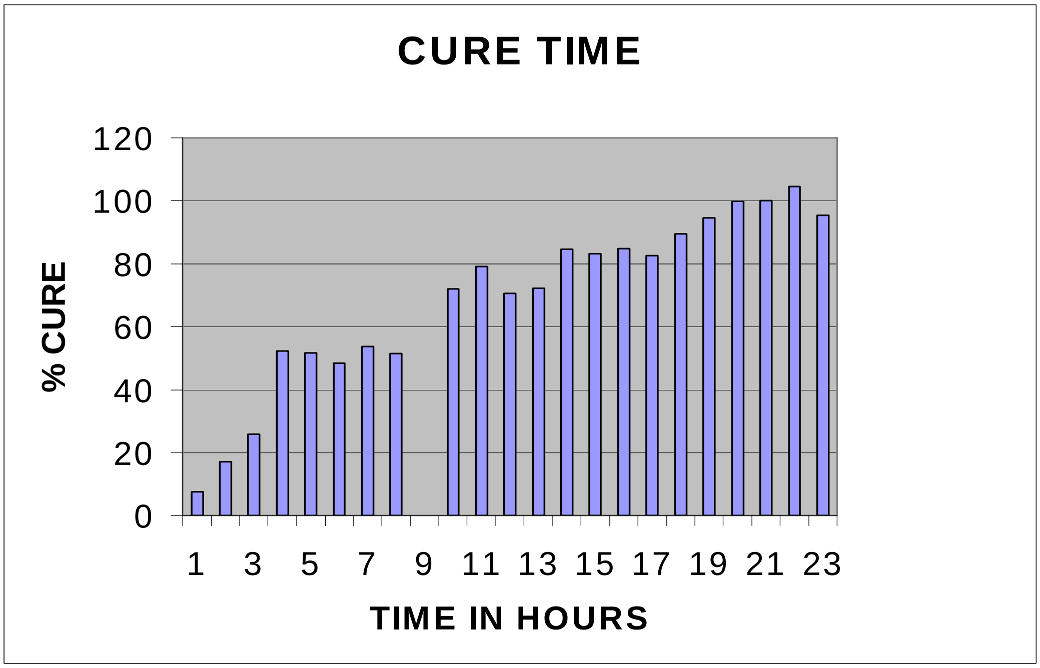
3.12 Salt Water Soak: The tensile strength of the processed panels after 8000 hours and reference panels are as follows. Note that the test is continuing and will run to 10,000 hours.

3.12 TENSION	THICKNESS (inches)	AREA SQUARE (inches)	ULTIMATE LOAD (pounds)	TENSILE STRENGTH (psi)	TENSILE MODULUS (e^6)	STRENGTH PER INCH PER PLY (pounds)
BASELINE	0.1024	0.1022	4,799	46,957	3.0	1,202
PROCESSED PANEL 8000 HOURS	0.1202	0.1215	4,466	36,757	2.4	1,116

Test numbers 263 and 2276. There was a slight softening and swelling of the resin, which increased the thickness of the panel and reduced the tensile and modulus. The important parameter is that the strength per ply was reduced by only 8%. **Location L1.**

3.13 Tensile Properties at elevated temperatures: See paragraph 3.21 for creep-rupture test details. The slope of the load vs. cycles to failure for the room and elevated temperature (160°F) tests were the same and the offset between the plots is 9%. This indicates that the creep-rupture performance at the material at the elevated temperature is 9% lower than at room temperature.

3.14 Cure Time: The results of the cure time were converted into percent of the final interlaminar shear strength. These tests were completed on coupons over 0.25" thick to simulate the cure of a thick lay-up. Due to the coupon thickness, the data needed to be plotted and then analyzed to determine the actual cure times of each sample.



The conclusion is that the material cures to about 60% of its final strength in about 8 hours. **Location L1.**

3.15 Cathodic Disbondment: Test number 28184. The preliminary results of the test are 0.6 inches. Subsequent testing results showed no evidence of cathodic disbondment. **Location L4.**

3.16 **Chemical Resistance:** The results of the test are:

CHEMICAL	REACTION
Acetone	No Reaction
Diesel Fuel	No Reaction
Ethyl Alcohol	No Reaction
Gasoline	No Reaction
HCL (30%)	Slight Softening
MEK	No Reaction
Toluene	No Reaction

3.17 Impact Resistance: Test number 162527. The coupons had a Mean-Energy of 80 in.-lbf. **Location L5.**

3.18 UV Resistance: Two panels were prepared using our UV resistant resin formulation. The tensile strength of the processed panels and reference panels are as follows:

3.18 TENSION	THICKNESS (inches)	AREA SQUARE (inches)	ULTIMATE LOAD (pounds)	TENSILE STRENGTH (psi)	TENSILE MODULUS (e^6 psi)	STRENGTH PER INCH PER PLY (pounds)
BASELINE RESULTS	0.060	0.060	2,644	43,870	3.07	524
AVERAGE RESULTS	0.055	0.055	2,520	45,460	2.86	504

Test numbers are 800 and 801. The strength data between the two samples is less than normal to test variance. The conclusion is that the exposure had no effect on the coupons. **Location L1.**

3.19 Dry Heat: The tensile strength of the baseline and processed panels are as follows:

3.19 TENSION	TENSILE STRENGTH (psi)	TENSILE MODULUS (e^6 psi)
BASELINE (5011)	49,200	2.9
AVERAGE RESULTS - 1000 HOURS	50,200	3.2
AVERAGE RESULTS - 3000 HOURS	49,500	3.2
BASELINE (5050)	41,611	2.8
AVERAGE RESULTS - 1000 HOURS	44,400	2.8
AVERAGE RESULTS - 3000 HOURS	42,400	2.9

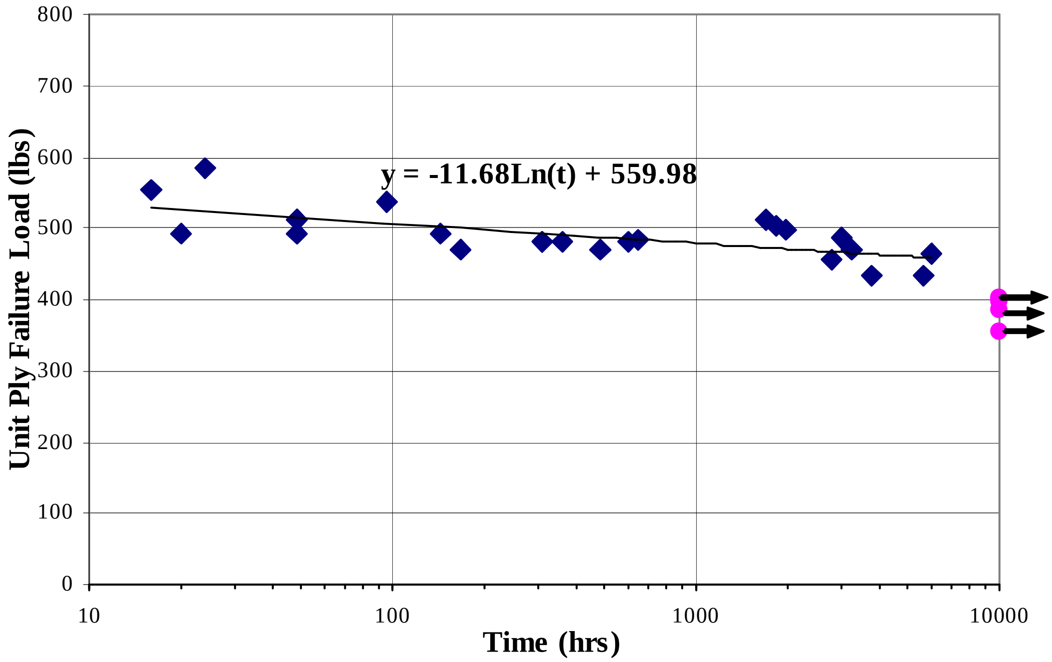
Test number 939799. The tensile and modulus data between the processed and baseline panels are essentially identical. **Location L7.**

3.20 Diesel Soak: The tensile strength of the processed panels and reference panels are as follows:

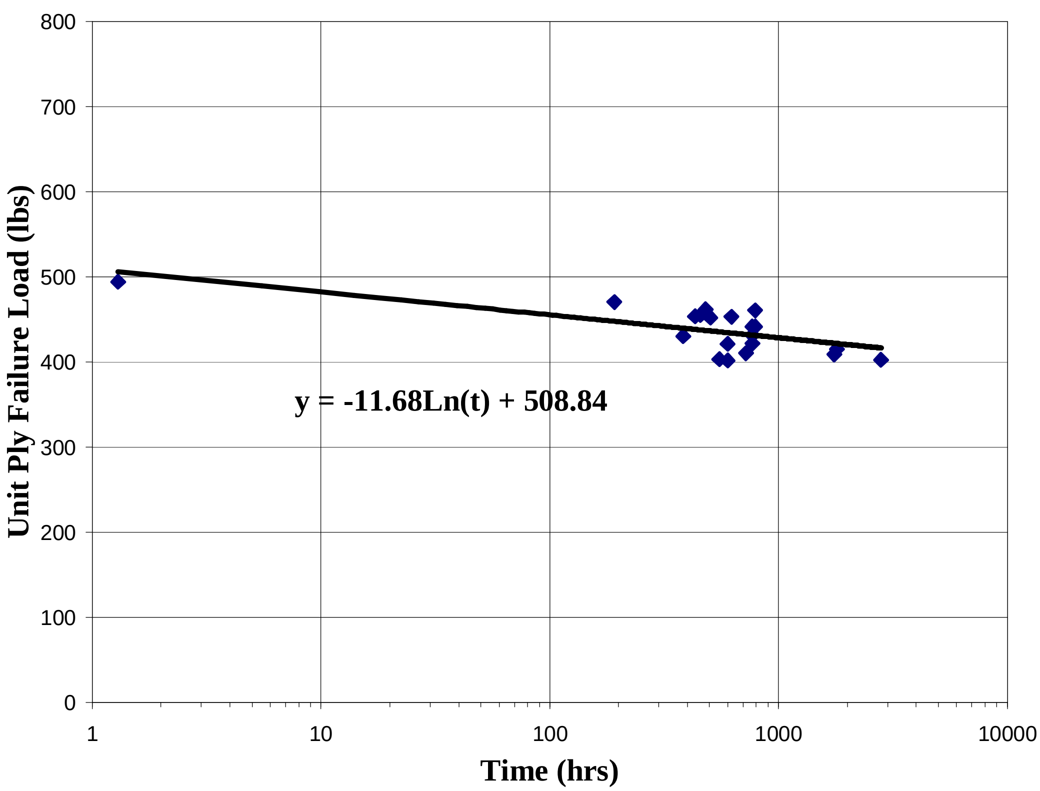
3.20 TENSION	THICKNESS (inches)	AREA SQUARE (inches)	ULTIMATE LOAD (pounds)	TENSILE STRENGTH (psi)	TENSILE MODULUS (e^6 psi)	STRENGTH PER INCH PER PLY (pounds)
BASELINE RESULTS	0.042	0.043	2,730	63,627	3.2	667
AVERAGE RESULTS	0.042	0.042	2,704	65,832	3.1	673

Test numbers are 1727 and 1726. The weight of the processed panel increased slightly during the processing from 65.6 grams to 67.1 grams. There does not appear to be any difference in the appearance of the panels and the Shore D Hardness of both panels was 90. The conclusion of the test is that there was no difference between the processed and baseline panel. **Location L1.**

3.21 **Creep Rupture:** Test number 907198. The results of the room temperature 10,000-hour test are shown in the following graphs:

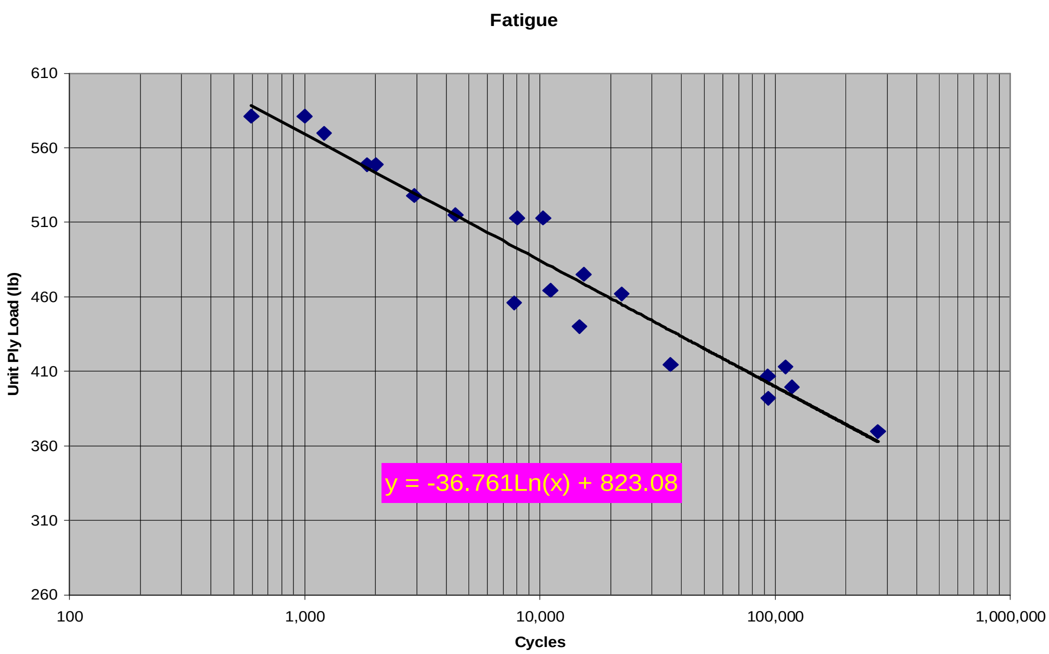


The baseline strength of this 11 oz. tape material is 801 pounds per ply. The 25-year projection of 416 pounds per inch represents a long-term load capability of 52% of its initial tensile strength. The results of the testing at 160° F are shown in the following graph.



First the slope of the room and elevated temperature plots is identical and the offset between them is 9%. This indicates that the long term load handling capability at elevated temperatures had a difference of only 9%. This is an excellent result. **Location L7.**

3.22 Cyclic Loading: Test number 907198A. The results of the testing to date are shown in the following graph. The baseline load per ply of this material is 801 pounds per ply. **Location L7.**



3.23 NSF Approval: **Aquawrap®** was tested by NSF International and was determined to comply with ANSI/NSF 61. As such, we are authorized to use the NSF mark on our products specified on the NSF listing. Certificate #37231-01. **Location L4.**

4.0 Burst Testing

4.1 Pipe Burst Test

Although multiple burst tests have been performed under a variety of conditions, the validation of the material should be based on its ability to contain the Maximum Allowable Operating Pressure of any given system. The following chart outlines results from a few of these tests.

Discussion of the Chart

- The first column outlines the pipe detail such as the outside diameter of the pipe, the original wall thickness of the pristine pipe, the grade of the pipe, the specified minimum yield strength (SMYS) of the pipe, and the ultimate tensile strength (UTS) of the pipe.
- The second column is the calculated yield pressure of the particular specimen. This is derived using Barlow's Equation (P=2ST/D).
- The third column is the calculated burst pressure of the particular specimen. This is also derived using Barlow's Equation.
- The fourth column represents the calculated maximum allowable operating pressure (MAOP) of the pristine pipe. This number uses 72% of the calculated yield pressure of the pristine pipe.
- The fifth column is a summary of the defect that was created in the pipe. It lists the length and width of the defect, as well as the depth. All defects were machined and measurements confirmed. Depth of the defect and the remaining pipe wall thickness were verified using calibrated ultrasonic testing equipment.
- The sixth column is the calculated burst pressure of the pipe specimen when the defect is entered into the equation.
- The seventh column indicates the number of layers of **Aquawrap® G-03 Fabric** that was applied and the approximate thickness of the lay-up.
- The final column lists the failure mode of the test.

Pipe Preparation

- All pipe specimens were verified for proper diameter and wall thickness.
- The pipe was cleaned to a near-white metal finish and then wiped with a solvent cleaner such as acetone.
- The filler material, or load transfer compound, was then applied in the defect area. Enough material was applied to restore the profile of the pipe. This was allowed to cure prior to subsequent steps.
- Proper primer was applied and the required number of layers of **Aquawrap® G-03 Fabric** were installed.
- Stricture Banding™ was used to compress and consolidate the final installation.
- The lay-up was allowed to completely cure prior to any pressure application.

Burst Testing

- A section of pipe was capped on both ends with welded end-caps. On opposite ends of the pipe specimen, ¾" threaded half couplings were welded on. One was to accept the pressurization hose and the other was used to bleed air during the filling process.
- Pipe was filled with ambient temperature water and all air was purged.
- Pressure was applied steadily throughout the test. On some instances, the pressure was held at particular stages for 5-10 minutes.
- Test was completed upon failure of the pipe specimen or the wrap itself.

Burst Test Results

PIPE DETAILS	PIPE YIELD PRESSURE	PIPE BURST PRESSURE	MAOP[1]	DEFECT DETAILS	CALCULATED BURST PRESSURE WITH DEFECT	CALCULATED BURST PRESSURE WITH REPAIRED DEFECT	LAYERS	RESULT
8.644" OD [2] 0.322" wall A53 Gr.B 44,000 SMYS 71,000 UTS (Serial #967296)	3,278 psi	5,290 psi	2,360 psi	External 8" long 4" wide 0.192" deep (59.6% wall loss)	2,136 psi	5,271 psi	38 layers (0.418")	Leakage under wrap at 5,100 psi
8.644" OD [2] 0.322" wall API 5L 44,000 SMYS 71,000 UTS (Serial #947996)	3,278 psi	5,290 psi	2,360 psi	External 8" long 4" wide 0.192" deep (59.6% wall loss)	2,136 psi	5,897 psi	44 layers (0.484")	Burst under wrap at 5,159 psi
12.75" OD [2] 0.250" wall ERW 54,000 SMYS 72,000 UTS (Serial #958497)	2,118 psi	2,824 psi	1,525 psi	External 6" long 1.47" wide 0.125" deep (50% wall loss)	1,412 psi	4,311 psi	62 layers (0.6875")	Pipe burst outside of wrap at 2,740 psi
16" OD [3] 0.250" wall ERW 50,000 SMYS 70,000 UTS (Serial #938098)	1,563 psi	2,188 psi	1,125 psi	External 8.50" long 4" wide 0.125" deep (50% wall loss)	1,460 psi [4]	1,513 psi	13 layers (0.143")	Wrap failure at 2,045 psi
20" OD [3] 0.562" wall API 5L X60 60,000 SMYS 87,747 UTS (Serial #899697)	3,374 psi	4,934 psi	2,428 psi	External 19.69" long 3.74" wide 0.370" deep (66% wall loss)	1,536 psi	3,204 psi	89 layers (0.984")	Held at 3,374 psi for a 4 hour test

1. Using a 0.72 design factor
2. Pipe specimens were prepared and wrapped at Air Logistics, Azusa, CA facility. Tests completed by a third party at their testing facility. Location L2.
3. Tests were conducted at the request of a third party. Installations and testing were done at their site, with their material and test equipment.
4. The calculated burst pressure with the defect was 1,094 using Barlow's formula and 1,213 using RSTRENG. Pressure indicated was derived from a ruptured test sample using similar corrosion depth, width, and length dimensions.

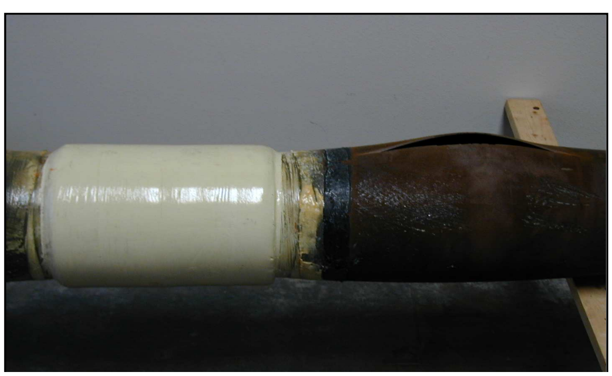


Figure 4.2
12.75" OD pipe with ruptured section adjacent to wrap.

4.2 Burst Test Evaluation

The following provides a simple background of each of the tests that were performed.

1. 8.644” OD Pipe (Serial #967296) -
   This test involved a pipe section with a machined defect measuring 8” long x 4” wide x .192” deep (59.6% wall loss). The pipe section was 60” long and closed at both ends with welded end-caps. Actual failure occurred within 3.5% of the calculated failure. This test provided very desirable results. Location L2.

2. 8.644” OD Pipe (Serial #967296) -
   This test was similar to the previous test done on 8” pipe, yet the test duration was longer. During the first pressure stage, the test piece was taken from 0 psi to 2,771 psi (over 400 psi beyond the MAOP of the pipe) in 90 seconds. It was then held at that pressure for 3 minutes. No drop in pressure or material damage was observed. The second stage increased the pressure from 2,771 psi to 3,265 psi, which is just under the yield point of the steel. Elapsed time to reach this pressure was 2 minutes, and it was held at that point for 3 minutes. The final stage was a slow increase in pressure until failure occurred. The duration of this stage was 10 minutes. This type of test was useful in qualifying previous tests done on the creep-rupture properties of Aquawrap®. This test resulted in a very successful outcome. Location L2.

3. 12.75” OD Pipe (Serial #958497) -
   This section of pipe had a machined defect measuring 6” long x 1.47” wide x .125” deep (50% wall loss). The pipe section was 60” long and closed at both ends with welded end caps. The wrap installation was fairly conservative, as the goal was to burst the pipe outside the wrap section. Using our current Aquawrap® Composite Wrap Reinforcement Calculator, the 62 layers that were applied equates to inputs of 400 pounds per ply for the material, using a 0.67 design factor for the composite, and a safety factor of 1.25. Location L2.

4. 16” OD Pipe (Serial #938098) -
   This test specimen was provided by a third party for testing at their facility. This test was designed to take the pipe over the yield pressure, as the normal operating pressure would never be expected to reach that point. The defect was 8.5” long x .125” deep (50% wall loss). The pipe section was 20 feet long and closed at both ends with welded end caps. A static burst test of a similar piece of pipe ruptured in the defect area at 1,406 psi. This pressure was used as the base to determine how much load the composite wrap was to hold.

5. 20” OD Pipe (Serial #899697) -
   The pipe specimen used in this test had a machined defect measuring 19.69” long x 3.74” wide x .370” deep (66% wall loss). The purpose of this test was to verify the capability of the composite to repair external defects. This test was comprised of three pressure cycles. The first cycle took the specimen to 90 percent of the design pressure of the piping (2,428 psi). After this, the pressure was relieved and the repair inspected for visual defects. The second pressure cycle took the specimen to the SMYS of the pipe (3,374 psi). It was held at this pressure for four hours and then the pressure was once again relieved. The last pressure cycle was composed of ten cycles that went from 0-2,428 psi. The repair passed all three test cycles for external repair of the defect. Location L9.

4.3 NOL Ring Test Data Summary

The NOL (Naval Ordinance Laboratory) ring test is done on a 0.20 inch thick, 1” inch wide ring of composite material, 20” in diameter. The ring is placed in a special test machine mounted outside of a bladder. The bladder is then pressurized with liquid, thus causing hoop stress to be applied to the entire ring simultaneously. The pressure is increased until the ring fails. The stress in the ring at failure is then compared to that of ASTM D 3039 coupon results. The reason this test was devised is that test results done on composite structures, such as rocket motor casings and infrastructure column reinforcements, did not always match those calculated using coupon test data. The reason for this is inadequate interlaminar shear strength of the composite. If the interlaminar shear properties of the composite are not good enough, the composite delaminates rather than fails in a normal tension mode. The NOL ring test was devised to measure the composite system under true hoop stress loading. Air Logistics has completed NOL ring tests on four of its materials; Glass Tape (G-03 Fabric), Glass Woven Roving (G-05 Fabric), UD Glass (G-06 Fabric), and UD Carbon (C-14 Fabric). Although this paper focuses on the G-03 Fabric, the other materials are included for reference. The NOL ring testing was performed at Alliant TechSystems Inc. (Location L8).

<u>Chart Layout</u>

- The first column is the coupon test number.
- The second column is the pressure at which the ring failed.
- The third column is the force on the ring at failure.
- The next four columns list the number of layers and the per layer strength of materials used to fabricate the ring.
- The next column is the total calculated force of the ring.
- The last column lists the difference between the actual test results and the calculated force.

<u>Discussion of Test Results</u>

In all cases the actual force the material withstood during the test was greater than that calculated based on the ASTM D3039 coupon test data. It should be noted that the pressurization rate of the rings generally resulted in failure in about 30 seconds. This rate is determined by the test machine and cannot be easily changed. The specified time to failure of coupons in the ASTM test is between one and ten minutes. The pull rate of the data taken on the coupons of the materials listed generally resulted in failure between two and four minutes. The creep rupture characteristics of these materials could explain the better results of the rings with respect to coupons.

NOL Ring Test Results

TEST NUMBER	PRESSURE AT FAILURE (psi)	FORCE (pounds)	PLIES G-03	PLIES OTHER	STRENGTH PER PLY G-03 FABRIC (pounds)	STRENGTH PER PLY OTHER FABRIC (pounds)	TOTAL CALCULATED FORCE (pounds)	DELTA FORCE (pounds)
G-03 FABRIC								
Ring 1	1,434	14,340	17		750		12,750	1,590
Ring 2	1,390	13,900	17		750		12,750	1,150
Ring 3	1,372	13,720	17		750		12,750	970
Ring 4	1,425	14,250	17		750		12,750	1,500
Average	1,405	14,053			750		12,750	1,303
G-05 FABRIC								
WR 7-101	1,132	11,320		7		1,200	8,400	2,920
WR 7-201	1,024	10,240		7		1,200	8,400	1,840
WR 7-301	968	9,680		7		1,200	8,400	1,280
Average	1,041	10,413				1,200	8,400	2,013
G-06 UD FABRIC								
SIR00101	2,189	21,890	1	8 (G-06)	750	2,400	19,950	1,940
SIR00102	2,357	23,570	1	8 (G-06)	750	2,400	19,950	3,620
Average	2,273	22,730			750	2,400	19,950	2,780
C-14 UD FABRIC								
SIR00103	3,003	30,030	2	8 (C-14)	750	3,400	28,700	1,330
SIR00104	2,680	26,800	2	8 (C-14)	750	3,400	28,700	1,900
SIR00105	2,868	28,680	1	8 (C-14)	750	3,400	27,950	730
SIR00106	2,890	28,900	1	8 (C-14)	750	3,400	27,950	950
Average	2,860	28,603			750	3,400	28,325	1,227

5.0 Test Locations

Location L1 Air Logistics Corporation 3600 East Foothill Boulevard Pasadena, CA 91107 Phone 626-795-9971	**Location L2** Authorized Testing Inc. 2522 Kansas Avenue Riverside, CA 92507 Phone 909-682-4110
Location L3 Delsen Test Laboratories, Inc. 1024 Grand Central Avenue Glendale, CA 91201-3011 Phone 818-247-4106	**Location L4** National Testing Laboratories 877 Rose Place Anaheim, CA 92805 Phone 714-991-5520
Location L5 SGS U.S. Testing Company, Inc. 5555 Telegraph Road Los Angeles, CA 90040 Phone 323-838-1600	**Location L6** University of Utah Civil & Environmental Engineering College of Engineering 122 South Central Campus Drive - Rm. 104 Salt Lake City, UT 84112-0561 Report No. CVEEN-03/01
Location L7 University of Wyoming Composite Materials Research Group PO Box 3295 Laramie, WY 82071 Phone 307-766-4266 Fax 307 766-2695	**Location L8** Alliant Techsystems Inc. Freeport Center PO Box 160433 Clearfield, UT 84016-0433 Phone 801-775-1729 Fax 801-775-1207
Location L9 Petrobras Research Center (CENPES) Luiz C.M. Meniconi Catholic University of Rio de Janeiro Jose L.F. Freire Ronaldo D. Vieira Jorge L.C. Diniz **Reference ASME Document IPC02-27372**	

6.0 Conclusion

Through laboratory testing and field testing, **Aquawrap®** has proven itself to be an easy to use, reliable, and efficient means of repairing piping that has been subjected to damage caused by external corrosion or by other mechanical means. The product has undergone extensive development to arrive at the final stage you see today. By testing many different resin formulations, fabric weaves and types, and the combination of both, Air Logistics was able to distinguish itself from other products in the same market. **Aquawrap®** is an engineered composite product, designed specifically for structural reinforcement.

By performing burst tests, we are able to see the actual performance of material in a real life situation. Most pipelines may never see their maximum allowable operation pressure, but testing to that threshold proves the viability of the product. The ability of **Aquawrap®** to be applied in layers provides the end user with the option of installing more strength to the system if they so choose. A minimum of four layers is recommended on any installation, regardless of strength calculation results. Air Logistics provides a simple calculation program that one can use to determine the number of layers required for a given repair.

Aquawrap® is an environmentally safe product which uses no hazardous chemicals. No measuring or mixing of resins is required and clean-up is safe and quick. Primer systems are prepackaged to ensure the right ratios, and are designed to be mixed in their own containers. This eliminates the need for extra mixing buckets, and extra waste.

Air Logistics will continue its commitment to provide high strength composites to the pipeline market. These products will help prevent system shut-downs, costly repairs, and damage to the environment.

Air Logistics Corporation, Pasadena, CA **March 2003**

Aquawrap Concrete Repair and Restoration System
[Factory Pregged (Saturated) Composite System]

Reinforced Concrete Beam Test Report

Structural Evaluation of Aquawrap Composite System for Repair and Strengthening of Reinforced Concrete Beams

Prepared for:

Air Logistics Corporation
3600 Foothill Blvd
Pasadena, CA 91107

Prepared by:
James Korff

Table of Contents

1. **Abstract**

This report provides results of the structural testing and evaluation of the Air Logistics "Aquawrap" Concrete Repair and Restoration System conducted on full-scale reinforced concrete beams. Loads and displacements were continuously monitored and recorded during the tests. A total of three (3) tests were conducted on beams strengthened with Air Logistics "Aquawrap" systems.

2. **Object Statement**

The purpose of testing was to evaluate the structural performance of reinforced concrete beams strengthened externally with Air Logistics "Aquawrap" Concrete Repair and Restoration System. Three strengthening configurations were tested, all in accordance with the recently released "Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures", as reported by ACI Committee 440 (ACI 440.2R-02).

3. **Introduction to Aquawrap System**

The Air Logistics "Aquawrap" Concrete Repair and Restoration System is a proven, engineered, field-applied composite system. It features a high mechanical strength, fast and simple installation, no field mixing, measuring or saturation, wide application temperature range, wet or underwater application, fast cure, and non-hazardous shipping.

It is an ideal system for concrete strengthening per ACI Publication ACI 440.2R-02 " Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures".

Aquawrap is a pre-impregnated, water activated, structural wrap that has been used successfully to repair and strengthen NYDOT and IDAHO DOT bridge columns and piers, and has also been tested extensively and utilized as a FRP Wrap for repairing damaged aluminum and steel freeway sign structures. The product has also been utilized in the repair of wooden utility poles and for pipeline reinforcement. Aquawrap consists of either glass fiber (Woven and UD) or carbon fiber (Woven and UD) sheets pre-impregnated with water cured polyurethane resin. The resin content is set at the factory. No impregnation equipment or effort is required at the job site. There is no field saturation required. The material comes in hermetically sealed pouches that are opened prior to use. The water activated polyurethane resin has a faster cure than most epoxy systems. It cures under ambient temperature, with a relatively high glass transition temperature. The wrap may be applied in cold temperatures (32 F.), and in wet conditions, even in the rain or under water.

4. **Identification and Dates of Tests**

A total of four (4) reinforced concrete beams were fabricated and a total of four (4) tests were conducted up to the ultimate capacity of each specimen. The test matrix is shown in Table 1.

TABLE 1

Test #	**Description**	**Test Date**
B0	As Built – No Composite Strengthening	Jan 17, 2003
B1	Two Layers of UD Carbon w/ Adhesive N0. 1	Jan 17, 2003
B2	Two Layers of UD Carbon w/ Epoxy Adhesive	Jan 17, 2003
B3	Two Layers of UD Carbon w/ Adhesive No. 1 and Fabric U-Strap Stirrups at ends.	Jan 17, 2003

5. Description of Specimens and Apparatus

5.1. Specimen Description

5.1.1. Reinforcement

All beams were fabricated using Grade 60 reinforcing steel from the same mill batches. Beam widths were 4 in. Beam depths were 7 in. Tension (bottom) reinforcement consisted of two (2) #3 steel with a one-inch cover of concrete. One (1) #3 steel bar was placed at the center at the top of the beam with a one-inch cover of concrete. Shear reinforcement consisted of #3 stirrups spaced evenly along the beam ends. The clear span of all beam specimens was 6 ft 1 in. Beams had a centerline in each direction.

5.1.2. Concrete

Concrete with a nominal compressive strength of 6,000 psi was used in the construction of each beam. Four (4) beams were fabricated. All beams were poured from the same batch of concrete. Specified concrete mix design was for 28-day strength of 6,000 psi.

5.1.3. Aquawrap Material Properties

UD Carbon

Tensile Strength = 120,000 psi

Tensile Strength per inch width = 3,400 lbs

E-Modulus = 11,000 ksi

Elongation at break = 1.1 %

5.2. Test Assembly

The concrete beams were simply supported at either end and a vertical downward load applied at two points along the top of the beam (Four-point Loading). All test specimens were fabricated on site at Air Logistics Corporation, Pasadena, CA, under continuous supervision of the program manager. The test assembly and the special transfer fixtures were designed and calibrated to perform this type of full-scale beam evaluation test. The test actuator was a located between the actuator and the test specimen.

6. Testing Program

6.1. Test protocol

One (1) as built full-scale beam (without composite materials) was tested to failure. The purpose of the test was to evaluate the ultimate flexural strength of the beam and to identify modes of failure.

As built beams and beams strengthened with the Aquawrap systems were then tested to ultimate failure. Aquawrap systems were bonded to the reinforced concrete beams with either polyurethane or epoxy adhesives.

Weak concrete on the tensile surface of the beams to be strengthened was prepared with a needle scaler to produce a surface similar to that achieved with high pressure water or sand blasting.

Four point bending tests were performed on all beams. Deflections at the midspan of the beam were measured.

6.1.1. Loading

For all tests, the load was applied using a four-point loading configuration with a constant rate of loading of about 1 kip per minute ramp. Loads were applied monotonically in a vertical downward direction until failure occurred and the beam would no longer sustain a load.

6.1.2. Environmental Conditions

Test was performed at the testing facilities of Air Logistics Corporation. The average temperature and average relative humidity were 62 degrees F., and 55 % respectively.

7. Test Results

Test Results of flexural tests for control and strengthened beams are shown in Table 2, and their load deflection curves are shown in Appendix I. The Aquawrap strengthening with UD Carbon fabric significantly increased the flexural capacity of the beams with a corresponding increase in flexural ductility. The failure moments were in excess of the nominal moment capacities predicted using the strain compatibility procedures and approach described in the ACI 440R-02 report.

7.1. Control Specimen

In the control beam tested, no cracking was observed at low load levels. Afterwards, cracks first developed between the two points of loading in the constant moment region. Cracks increased with increased loading. Flexural failure of the control beam due to concrete crushing occurred at a load of approximately 6280 lbs with a corresponding deflection at midpoint of 0.315 ins.

7.2. Strengthened Specimens

7.2.1. Aquawrap Strengthening Schemes

As per Table 1, three (3) different strengthening schemes were tested.

7.2.1.1.
B1 was strengthened with two layers of Aquawrap UD Carbon fabric bonded to the beam with Aquawrap Urethane Adhesive No. 1.

7.2.1.2.
B2 was strengthened with two layers of Aquawrap UD Carbon fabric bonded to the beam with Aquawrap Underwater Epoxy Adhesive No. 3

7.2.1.3.

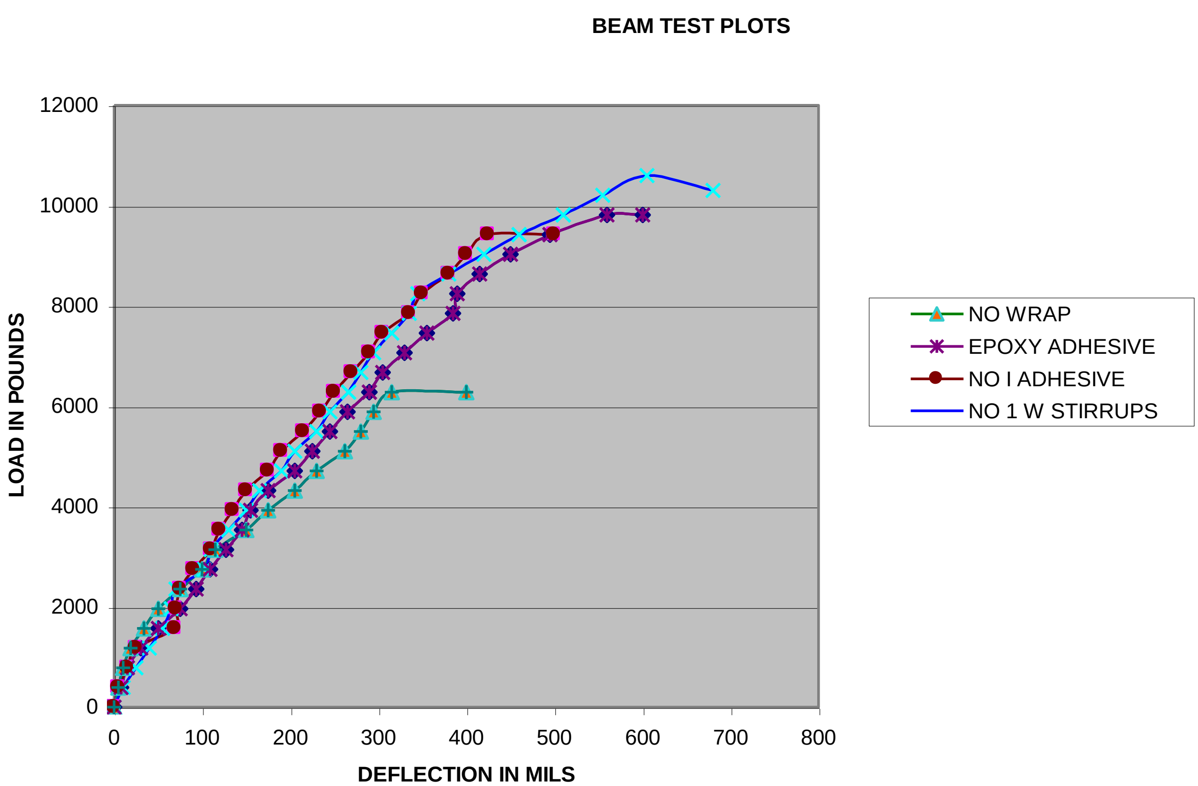
B3 was strengthened with two layers of Aquawrap UD Carbon fabric bonded to the beam with Aquawrap Urethane Adhesive No. 1. Additionally, U shaped Aquawrap stirrups at the ends of the reinforcement for additional anchorage, in accordance with recommendations of ACI 440R-02, were provided.

7.3. Summary of Results

TABLE 2

Beam	**Ultimate Load (pounds)**	**Deflection (in)**	**Increase in Capacity**
B0	6,280	0.315	-------
B1	9,420	0.425	50 %
B2	9,813	0.560	56 %
B3	10,598	0.605	69 %

Graph of Beam Test Results



The beams and their composite wraps were carefully examined after the tests and there was no evidence of voids or debonding from the concrete.

7.4. Conclusion

Aquawrap Pre-Pregged UD Carbon fabric bonded longitudinally with adhesives to the bottom of the reinforced concrete beams in accordance with procedures outlined in ACI 440R-02 strengthened the beams significantly, increasing their flexural strength over that of the control beams without reducing the beam ductilities.

Shear and normal stress concentrations occur near the ends of the FRP reinforcement. To ensure a flexural mode of failure, guarding against such stress concentrations, the longest possible bonded lengths were utilized. . As expected, the additional bond supplied at the ends by utilizing fabric U-Shaped straps contributed to additional flexural performance.

7.4.1. Increase in Capacity

Results of the tests performed showed a substantial increase in the flexural capacity of the strengthened beams versus the control reinforced concrete beams. This increase ranged from 56% to 69% over the capacity of the control beam. This increase in flexural capacity is within the limits of established guidelines for reinforcing with FRP sheets. As per the ACI 440R-02 and other guidelines, FRP reinforcement should be used only as supplemental reinforcement. This is to guarantee that in the event of loss of the FRP reinforcement, due to fires, vandalism or other such events, the structural member will remain capable of sustaining dead and live loads, although with much more deflection than in the service limit states.

7.4.2. Mode of Failure

FRP reinforcement can fail in two basic ways; flexural and local. The flexural mode of failure includes crushing of concrete or rupture of the FRP reinforcement. The local mode of failure can involve debonding of the FRP sheets or a shear failure of the concrete layer between the FRP and the longitudinal reinforcement. The flexural mode of failure supports a ductile behavior of the reinforced concrete element and is thus desirable. Local failures are to be avoided. Bond strength between the FRP and the concrete is thus a crucial factor affecting the structural response of the member.

The underlying purpose of the above beam testing was to verify the high level of performance of the Aquawrap FRP System. Failure of the above Aquawrap strengthened beams, whether with urethane adhesive or epoxy adhesive, consistently occurred as compression failures of the concrete. There was no failure in the Aquawrap composite FRP system.

PRODUCT TECHNICAL DATA SHEET

Aquawrap® G-03 & G-05

Highly Conformable Tape and Woven Roving Fabric Constructions

Aquawrap® is a low cost composite system for use in repair and reinforcement of existing mechanical systems, structures and piping. Furnished factory-impregnated with the proprietary 22-77 resin system. It is odorless and solvent-free. Cured Aquawrap® is a very durable, high long term strength material, impervious to fuels, most chemicals and solvents. It permanently bonds to a wide variety of surfaces such as metals, composites, concrete, plastics and wood. Certified to NSF/ANSI Standard 61. Qualified in accordance with the ASME PCC-2 piping repair standard.

Aquawrap® is ready to apply, right out of the bag and cures by way of a chemical reaction with field-applied water. This offers considerable advantages over conventional cloth-resin systems in that there is no resin measuring, mixing, spreading, solvents, or dripping polymer mess.

PRODUCT PROPERTIES			
Working Time:	30-40 min. at 25°C (77°F)	**Mix Ratio:**	No mixing required
Application Temps:	4-93°C (40-200°F)	**Service Temps:**	-40°C - 121°C (-40°F - 250°F)
Cure Time (dry to touch):	30-60 minutes at 25°C (77°F)	**Full Cure:**	7 days at 25°C (77°F)
Usual Packaging:	Pre-Packaged Rolls	**Shelf Life:**	1 year
Chemical Resistance:	Acetone, mek, toluene, gasoline, ethyl alcohol and many others	**Hardness:**	90 Shore D - ASTM D-2240

COMPOSTIE PROPERTIES		
TEST	G-03 FABRIC	G-05 FABRIC
Tensile Strength (warp direction). psi	52089	46525
Tensile Strength (fill direction), psi	26236	46525
Tensile Modulus (warp direction), msi	2.78	2.63
Tensile Modulus (fill direction), msi	1.34	2.63
Tensile load per ply (warp direction), pounds per inch of width	814	1175
Tensile load per ply (fill direction), pounds per inch of width	457	1175
Thickness, mils	15.5	25.5
HDT, ^{O}F	325	325
CTE,in/in ^{O}F	8.2 e^{-6}	NA
Tg ^{O}F	288	288
Bond strength to steel with BP-1 Adhesive, psi	1360	989

ATTENTION: All of the following data are based on laboratory conditions, at room temperature. Field conditions can radically change the characteristics of this product. Higher temperatures will lessen the working life of the product. Allow adequate time for application. Field testing is strongly recommended prior to application.

Design and Application Instructions

Design guidelines, application notes and wrap calculations for various applications are available from the factory.

Storage

Store at 60-90° F in a dry place. Keep from freezing. Dispose of any leftover material.

Handling

Aquawrap® is shipped in a sealed protective bag to protect it from atmospheric moisture. Because it cures with the application of water (and air humidity), care must be taken in handling the sealed bags to prevent puncturing or scuffing, which would cause the product to cure in the bag. Once the bag is opened and the Aquawrap® is exposed to the humidity in the air, it will begin to cure and will gel within about 60 minutes. Therefore, work must be well planned prior to opening the bag. Aquawrap® requires no other special handling or application procedures. This resin is slightly irritating to certain sensitive people; it will give off a small amount of carbon dioxide vapor while curing; and the cured resin is permanent and very difficult to remove, so gloves, safety glasses and other personnel protection equipment appropriate for the task must be used.

Shelf Life

12 months from date of sale, in an unopened package, stored in cool warehouse conditions.

Caution – Read MSDS prior to use. Some persons may be irritated by this compound. Use caution and PPE. This product is for industrial use by professionally trained personnel only. Please read and understand all application instructions prior to using.

Warranty

The manufacturer warrants that the goods delivered hereunder shall be free from defects in material and workmanship. The WARRANTY shall extend for a period of one (1) year after date of delivery of such goods to customer. This warranty is void in the event that the protective pouch has been damaged. THE MANUFACTURER MAKES NO WARRANTY EXPRESS, IMPLIED, (INCLUDING BUT NOT LIMITED TO WARRANTIES OF MERCHANTABILITY AND FITNESS FOR INTENDED PURPOSE), OR STATUTORY, OTHER THAN THE FOREGOING EXPRESS WARRANTY. Failure of customer to submit any claim hereunder within the Warranty Period after receipt of such goods shall be an admission by customer and conclusive proof that such articles are in every respect as warranted and shall release the manufacturer from any and all claims for damage or loss sustained by customer. In the event customer submits a claim for defective material within the required Warranty Period, the parties agree that customer's sole and exclusive remedy shall be the replacement of such defective goods or a refund of the price of the defective goods. To the greatest extent practical defective goods shall be returned to the manufacturer for analysis. IN NO EVENT SHALL THE MANUFACTURER BE LIABLE FOR INCIDENTAL OR CONSEQUENTIAL DAMAGES OR SPECIAL, INDIRECT OR INCIDENTAL DAMAGES ARISING OUT OF, OR AS THE RESULT OF, THE SALE, DELIVERY, NON-DELIVERY, LOSS OF USE OF GOODS OR ANY PART THEREOF, EVEN THOUGH THE MANUFACTURER HAS BEEN NEGLIGENT OR HAS BEEN INFORMED OF CIRCUMSTANCES WHICH MIGHT GIVE RISE TO SUCH DAMAGES.

Data and parameters listed herein and in our data sheets have been obtained by Air Logistics Corporation using materials under carefully controlled conditions. Data of this type should not be used by engineers as design specifications, but rather as indicative of ultimate properties obtainable. Before using, user should determine the suitability of the product for its intended use. In determining whether the material is suited for a particular use, such factors as overall application configuration and design, field conditions and environmental criteria to which it will be subjected should be considered by the user.

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PRODUCT TECHNICAL DATA SHEET

Aquawrap® Black

High Strength/Modulus Carbon Fabric Construction

Aquawrap® Black™ is a high strength high modulus repair and reinforcement system for existing mechanical systems, structures and piping. This product is especially suited for the economical repair of large piping systems. Furnished factory-impregnated with our proprietary urethane resin system. It is odorless and solvent-free. Cured Aquawrap® is a very durable, high long term strength material, impervious to fuels, most chemicals and solvents. It permanently bonds to a wide variety of surfaces such as metals, composites, concrete, plastics and wood.

Aquawrap® is ready to apply, right out of the bag and cures by way of a chemical reaction with field-applied water. This offers considerable advantages over conventional cloth-resin systems in that there is no resin measuring, mixing, spreading, solvents, or dripping polymer mess.

PRODUCT PROPERTIES			
Working Time:	30-40 min. at 25°C (77°F)	**Mix Ratio:**	No mixing required
Application Temps:	4-93°C (40-200°F)	**Service Temps:**	-18 - 121°C (0 - 250°F)
Cure Time (dry to touch):	30-60 minutes at 25°C (77°F)	**Full Cure:**	7 days at 25°C (77°F)
Usual Packaging:	Pre-Packaged Rolls	**Shelf Life:**	1 year
Chemical Resistance:	Acetone, mek, toluene, gasoline, ethyl alcohol and many others	**Hardness:**	90 Shore D - ASTM D-2240

TEST	C-2 FABRIC
Tensile Strength (warp direction). psi	77605
Tensile Strength (fill direction), psi	48,330
Tensile Modulus (warp direction), msi	6.45
Tensile Modulus (fill direction), msi	3.65
Tensile load per ply (warp direction), pounds per inch of width	2897
Tensile load per ply (fill direction), pounds per inch of width	1787
Thickness, mils	.037
HDT, ^{O}F	325
CTE,in/in ^{O}F	8.7 e^{-6}
Tg ^{O}F	288
Bond strength to steel with BP-1 Adhesive, psi	1000 (est)

ATTENTION: All of the following data are based on laboratory conditions, at room temperature. Field conditions can radically change the characteristics of this product. Higher temperatures will lessen the working life of the product. Allow adequate time for application. Field testing is strongly recommended prior to application.

Design and Application Instructions

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Storage

Store at 60-90° F in a dry place. Keep from freezing. Dispose of any leftover material.

Handling

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Shelf Life

12 months from date of sale, in an unopened package, stored in cool warehouse conditions.

Caution – Read MSDS prior to use. Some persons may be irritated by this compound. Use caution and PPE. This product is for industrial use by professionally trained personnel only. Please read and understand all application instructions prior to using.

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