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FINAL REPORT

on

EVALUATION OF THE AQUAWRAP® COMPOSITE REPAIR SYSTEM

to

AIR LOGISTICS CORPORATION

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by

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INTRODUCTION

Aquawrap® is a composite repair system for the rehabilitation of pipelines developed by Air Logistics Corporation's FACS Group. It is comprised of a proprietary polyurethane formula and custom-woven biaxial glass fiber. The installation requires a base primer to provide a proper bond of the Aquawrap® to the surface being repaired. Aquawrap® is then installed, utilizing water as an activator. Aquawrap® is a flexible system that is easy to install because the resin matrix is not cured until after the wrap is installed. Air Logistics Corporation has asked Kiefner and Associates, Inc. (KAI) to review the coupon and full-scale testing that Air Logistics Corporation has performed on the Aquawrap® repair system and for KAI to express their opinion as to whether it is an effective repair system for pipelines.

CONCLUSIONS AND RECOMMENDATIONS

- The design criteria used for Aquawrap® is conservative and conforms to the requirements of the soon-to-be released ASME PCC-2, Repair Standard Article 4.1, Non-Metallic Composite Repair Systems for Pipelines and Pipework: High- Risk Applications.
- The coupon testing carried out on Aquawrap® is complete and measures the properties that are relevant to the determination of a design life of the product. Although not required, we recommend that a test be performed to determine the composite's susceptibility to acidic soil conditions.
- The full-scale testing on Aquawrap® demonstrates that it can be used to repair corrosion, dents, and some forms of mechanical damage. We recommend that the repair of mechanical damage be determined on a case-by-case basis.
- The Air Logistics Corporation's quality-assurance program is complete.

TECHNICAL BACKGROUND

Composite wrap repairs have been used to repair corrosion, dents, and mechanical damage in pipelines. These repairs are effective because of restraint of radial displacement of a defect-weakened area when acted on by internal pressure. In order for this restraint to be effective, two things must happen. First, the defect-weakened area of the pipe being repaired must deform to transfer the load onto the composite. Second, the composite repair must be stiff enough and strong enough to accept this load. The effective stiffness (elastic modulus times the thickness) of the composite controls the amount of load that is transferred. The strength of the composite controls the amount of load the repair can sustain.

The paragraph above indicates that a composite repair is a complex system, which must be properly designed and installed if it is to be safe and effective. There are two components to the design process.

- The first is a ***verified*** design procedure that enables the designer to determine the proper configuration of the composite repair. This procedure can range (in order increasing conservatism) from a complete numerical simulation (i.e., finite- element analysis) of the repair, to the use of design equations through rules of thumb. What is critical is that this procedure is verified before use.
- The second component is knowledge of the properties of the composite repair. The repair must be designed so that it maintains the integrity of the repaired pipe in the environment in which it must operate for the design life of the repair with a sufficient margin of safety. Normally this means that a test program must be carried out on the repair system. These tests can be laboratory coupon tests, full-scale tests, or a combination of both.

Given the engineering required to design and install a composite repair system, the maintenance of sound quality standards are required to ensure that all aspects of the composite repair from manufacture through installation are properly carried out.

The remainder of this report will focus on our review of the design, testing, and quality of the Aquawrap® composite repair based on our review of reports provided to KAI by Air Logistics Corporation and conversations with Air Logistics personnel. The main focus will be on the results of the testing of the repair's properties used for design purposes and test that have been used to demonstrate the effectiveness of the repair for certain types of defects.

The following reports were reviewed in preparing this report.

- Worth, Franz, PE, "Analysis of Aquawrap® for use in Repairing Damaged Pipelines-Environmental Exposure Conditions-Property Testing Procedures-Field Testing Evaluations", Air Logistics Corporation, F.A.C.S Group (September 28, 2005).

- Alexander, Chris, "Evaluation of the Aquawrap™ System in Repairing Mechanically-Damaged Pipes", PN114315CRA, Stress Engineering Services, Inc., Revision 2 (September 2005).
- Product brochure titled "Aquawrap®" published by Air Logistics Corporation (copyright 2004).

In addition, we reviewed the Air Logistics and other Air Logistics supplier's websites for information about Aquawrap®. Lastly, Frantz Worth of Air Logistics Corporation was available to answer any additional questions we had.

DESIGN PROCEDURE

The Aquawrap® design procedure is based on the equation outlined in the soon-to-be-released ASME PCC-2, Repair Standard Article 4.1, Non-Metallic Composite Repair Systems for Pipelines and Pipework: High-Risk Applications. The relevant equation is in Section 3.4.5 titled "Repair Laminate Allowable Stresses Determined by Performance Testing". This equation is based on the composite repair being able to sustain the entire pressure load. The long-term strength used as a basis for this equation was determined by performance testing, which will be discussed under the testing portion of this report. This approach results in a conservative design since it does not take credit for the remaining pipe cross section. Aquawrap® has two calculators that are used to determine the number of wraps required for pipe repairs. One calculator is used for corrosion repair, and the second is used for dent repair. Air Logistics limits the distribution of these design calculators to its distributors and trained customers.

Air Logistics is careful to point out the limitations of the Aquawrap® repair system in its Aquawrap® brochure. These limitations include its unsuitability for active leaks, limits on the application and operating temperature, limits on chemical exposure, excessive matrix exposure to sunlight and some air-pollution elements, rotted away pipe or surfaces that are so bad that they cannot be cleaned, and protection of the composite from back-fill rocks and debris impacting the repair. In general, these limitations would apply to most composite repair systems and we think that it is an important aspect of the design process that these limitations are understood.

PRODUCT TESTING

Air Logistics has carried out an extensive test program on their product, which includes coupon-scale testing and full-scale testing. The purpose of the coupon testing is to determine the safe design stress for the repair material, ensure that its components meet certain design requirements, and determine the safe environmental operating parameters for the repair. For example, the stress-rupture testing is used to determine the design life of the repair. Another example is the use of the glass transition temperature to determine the maximum safe operating temperature for the repair. A list of the coupon- scale tests that have been performed are shown in Table 1. Full-scale testing can be used to determine the design factors described for the coupon testing. This approach demonstrates the suitability of the repair method for repairing specific defect types. The full-scale tests that have been performed are shown in Table 2.

QUALITY CONTROL

The document written by Franz Worth listed in the Technical Background section contains a section titled “F.A.C.S.™ Group Quality Overview”. This section begins with a quality objective, which is stated to be: “To produce a high quality product having outstanding performance characteristics with consistent handling and mechanical properties coupled with excellent longevity”. The document goes on to describe the quality assurance that goes into the design, development and qualification testing, workmanship practices, and test facilities. Of specific interest is the section on workmanship practices. It contains an outline of the procedures for control of incoming raw material, maintaining material traceability throughout the production process, maintaining packaging quality, product testing, and customer feedback. Finally, it was established through a phone conversation with Franz Worth that Air Logistics Corporation has a training program to certify customers for installing Aquawrap®. This program is a 2-day class, which contains a combination of classroom instruction and hands on training. The installer is required to be recertified every 3 years.

DISCUSSION

The design procedure that Air Logistics uses for the Aquawrap® is based on the assumption that the composite wrap must be strong enough to sustain the pressure load on the pipe. This is a conservative design approach since it does not take credit for the remaining wall thickness in the defect and the support provided by the pipe surrounding the defect. The only place we see where this approach might not be conservative is in the case of a fully circumferential defect, if the pipe is subject to high axial loads or if the defect is a crack-line flaw. It is important to point out that these limitations apply to all composite repair wraps at this time. Given that Aquawrap® contains axially oriented fibers, it is likely that it can deal with axial loading and full circumferential defects better than purely circumferentially oriented repair products. It is conceivable that with proper design, a product such as this could be used to repair girth welds.

The coupon test program that was carried out on Aquawrap® is one of the most comprehensive test programs that we have seen. The strength of the composite wrap and adhesive bond has been established under a variety of conditions. The operating temperature range for the repair has been determined through the glass transition temperature of the matrix. The material resistance to a large number of agents has been determined. Its resistance to cathodic disbondment has been determined. The design life has been determined through creep rupture testing. Our only recommendation in this area would be the addition of a test to determine the resistance of Aquawarp® acidic soil conditions.

In addition to the coupon testing, Air Logistics has performed three full-scale test programs to demonstrate the ability of Aquawrap® to repair corrosion, dents with gouges, and mechanical damage. Although these tests can be used to determine the design parameters for a repair technology, they are usually used to determine the effectiveness of the repair method for a specific kind of defect. If the test contains sufficient documentation and is properly instrumented, it can be used to gain an understanding of how the reinforcement works. In this case, it is possible to extrapolate the results beyond the actual cases studied. On the other hand, if the data collected during a test is limited to a few variables, then test could be considered a demonstration of the repair technique and it is risky to extrapolate the data beyond the cases studied. We examined the results of the full-scale tests and it is our opinion that they should be considered demonstration tests. We bring this up not as a criticism of the results of the testing. There is nothing wrong with this type of testing. It is less expensive and frequently required by customers before they are willing to commit to using the technology. In the case of metal loss, dents, and dents with repaired gouges, the mechanism of reinforcement is pretty well understood and a safe range of reinforcement can be determined. With regard to mechanical damage in general, there is much ongoing research and the mechanisms of failure are not fully understood for a damaged pipeline, let alone a repaired damaged pipe. Therefore, we feel that it would be risky for a composite-repair manufacturer to advertise that their product can repair mechanical damage. It must be examined on a case-by-case basis.

Initially we had some concerns regarding the results published in the titled "Evaluation of the Aquawrap™ System in Repairing Mechanically-Damaged Pipes" since for one of the two samples tested the cycles to failure were essentially the same for the unrepaired, repaired with no grinding, and repaired-with-grinding Aquawrap®. Since then we were able to evaluate the repaired-with-grinding specimen and agree that it can be removed from the test results since the failure does not appear to have been in the repaired area. With this point removed, we agree with the report conclusion that the data shows that the life of the repaired specimens was higher than the unrepaired ones.

We have not done a complete quality audit on the Air Logistics quality assurance and training programs. The information that we were able to obtain from their testing report and talks with Mr. Franz Worth indicate that quality is an important part of the Aquawrap® manufacturing process. All of the important aspects of a quality program are in place. The program has a clearly stated objective, there is control over incoming material, material traceability is maintained throughout the manufacturing process, it includes company-wide workmanship standards, a product testing program, and finally a means for customer feedback.

Table 1. List of Coupon Tests Performed and Test Standards Used on Aquawrap®

Test	Standard	Property Measured
Tension	ASTM D-3039	Tensile strength, tensile modulus, and strength per ply measured at room and elevated temperature, cured under water, after alkali, salt water and diesel soak, exposure to dry heat*
Flexural strength	ASTM D-790	Flexural strength and modulus
Compressive strength	ASTM D-695	Compressive strength and modulus
Interlaminar shear	ASTM D-2344	Interlaminar shear using short beam shear
Glass transition temperature	ASTM E-831	Glass transition temperature
Flammability	ASTM E-84	Flame spread and smoke density
Burst strength	NOL ring	Strength per ply
Lap shear	ASTM D-3165	Bond strength with steel, stainless steel, aluminum, steel under water, steel 1,000-hour soak, and thermal cycling
Chemical resistance	ASTM D-543(A)	Chemical resistance to acetone, diesel fuel, ethyl alcohol, gasoline, HCL (30 percent), MEK, and Toluene
NSF Approval	NSF Std 61	Approved for contact with potable water
Cure time	ASTM D-2344	Cure time
Impact resistance	ASTM D5420-98a	
Cathodic disbondment	ASTM G-8	Resistance to cathodic disbondment
UV resistance	ASTM D-2565	Remaining strength after UV exposure
Creep rupture	Modified ASTM D-2990 and D-2992	Long-term tensile performance
Cyclic loading	ASTM D-3039	Fatigue resistance
* Tensile modulus not measured in all cases.		

Table 2. List of Full-Scale Tests that have been Performed on Aquawrap®

Type of Test	Purpose
Burst	Repair of corrosion defects under static loading
Dent/Gouge	Repair of dents with gouges under cyclic loading
Mechanical Damage	Repair of mechanical damage under cyclic loading