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USING NON-METALLIC COMPOSITE MATERIAL FOR HIGH TEMPERATURE PIPING REPAIRS

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Composite, High Temperature, Pipe Repair, Flare Line, Maintenance, Processing, Epoxy, Fiberglass

ABSTRACT
As composite repair systems continue to become a routine repair option utilized by the refinery and chemical plant industry for the repair and rehabilitation of piping systems, the demands on performance characteristics are increasing as well. With any young repair methodology, the limits are continually tested, and the material must keep pace with industry need. While composites are not necessarily a new repair material option, when considered against other traditional repair methods, they are still in the relatively new stages of use and acceptance.

With many of the piping systems requiring repair being process lines which run at elevated temperatures, new composite repair systems and techniques are being developed to meet the demands of the industry to make safe and effective composite repair systems which can handle the continuous high operating temperatures of the piping systems. Numerous industry organizations are now recognizing composite repair systems as a reliable and effective means to repair corrosion damage, mitigate corrosion concerns, and keep critical piping systems in production. Since 2006, several industry standards and regulations have been published which can give proper guidance for the end user of the composite repair system and give a level of comfort and acceptance that the repair has been successfully tested, qualified, designed, and installed.

This paper will discuss the testing completed for a fiberglass and epoxy composite material designed for use with high temperature piping. The test results for compliance with industry standards will be shown as well as a case study for a practical and successful field use to show the practical results and benefits of using composite repairs in real world scenarios.

INTRODUCTION
The cost of corrosion is continuing to grow. Now well into the billions of dollars per year in the United States alone, the effects of corrosion on operations and efficiency is a constant drain on resources. The aging infrastructure of most processing plants around the world has helped to lead many into exploring new opportunities for implementing new and suitable repair technologies, which would allow production to continue during and after the repair procedure. With the increasing pressure to create safe work environments while also continuing to maximize efficiency and thereby profits, composite repair systems have become a very attractive repair method. Refining, processing and chemical plants have begun to recognize the many advantages of using composite materials to repair their pipe network.

While the operating pressures are not always extremely high, the chemicals used and the elevated temperatures of some of the process piping accelerate corrosion, both internal and external. In most cases, the wall loss is quite severe and in many cases has become a safety hazard or is even already leaking. Complete wall loss and pinhole leaking is a regular occurrence within many facilities, and in order to repair these types of defects, a composite system must meet the minimum requirements and perform at the expected level under extreme conditions.

Numerous composites are available on the open market today, but there are few that have the testing and capability to perform at the elevated temperatures which may be experienced. With this in mind, a new composite solution was researched, tested, and qualified to be used as a successful repair material in these harsh conditions.

USING COMPOSITES FOR REPAIRING PIPING

The use of composite technologies for repairing steel pipe has gained a large amount of support and acceptance as a viable option for owners/operators. The ASME and ISO organizations both introduced standards specifically for the qualification testing, validation, application, inspection, and certification of composites as used in the repair of high risk piping.

The ASME PCC-2 document, containing the article specific to composite repairs (Article 4.1 – Nonmetallic Composite Repair Systems for Piping and Pipework: High Risk Applications) was originally released in 2006. It has since published a revised document in 2011. The ISO/TS 24817 (Technical Specification for Petroleum, petrochemical and natural gas industries — Composite repairs for pipework — Qualification and design, installation, testing and inspection) was also released in 2006. It has not yet released a revision. Each of these documents outlines all requirements for a composite system to be qualified, as well as the installation technician to be properly trained and certified, in great detail. These documents have allowed plant maintenance departments all over the world to have a defined industry guideline on which to base their decisions and, in essence, judge whether a composite repair system has been properly tested and validated as suitable for their piping networks.

The testing requirements for a composite repair system in the ASME PCC-2 document are summarized in Table 1 included in Article 4.1. (Figure 1) These are the general requirement that each composite system must complete in order to be considered for use on pipes which are operating under high risk circumstances. However, this is simply the minimum requirement, and in order to fully understand how a composite system will withstand the intended use, additional testing should be done to fully validate the operating characteristics.

DEVELOPMENT FOR HIGH TEMPERATURE COMPOSITE REPAIR

With regards to composite repair systems being utilized on high temperature piping, of great concern is degradation of tensile strength and lap shear bonding to the pipe surface. While most epoxies perform admirably under room temperature conditions, when applied to elevated temperature there is a tendency of the material to lose some or all of its original design characteristics. In order to fully justify design requirements as stated in the industry standard, a composite repair system has undergone several stages of testing in order to develop an appropriate blend of design characteristics and field use. In order to fully understand the impact of temperature degradation, the system was tested under ambient conditions as well as exposure to high temperatures to determine if the system would be suitable for high temperature applications as well as to measure any degradation for design factor consideration.

A target temperature of 300° F (149° C) was used as a guideline for the desired upper limit for the repair system. With this in mind, the elevated temperature testing completed on each of the systems was completed at 300° F (149° C) to gauge the suitability of the repair system at this upper operating limit. Four different mechanical characteristics of the systems were evaluated as a part of the development process to determine the appropriate final system characteristics and usage limits.

- Tensile Strength
- Tensile Modulus
- Lap Shear Strength
- Direct Pull-Off Bond Strength

By looking at the degradation values based on the drop in each of these strengths, one can more accurately estimate the effectiveness and suitability for this system to be utilized for the repair of high temperature piping. This is also an important consideration when designing a composite repair system, as the tensile strength which is used in the design of the system should account for the value that it will be when exposed to the elevated temperatures. This is a critical factor in the required thickness of the repair, for example as determined by Equation 11 in Article 4.1 of the ASME PCC-2 document.

$$t_{repair} = \left(\frac{PD}{2} - t_s s\right) \cdot \left(\frac{1}{f s_{lt}}\right)$$

Where:

t_{repair} = design repair thickness
P = internal design pressure
D = external pipe diameter
t_s = minimum remaining wall thickness of the pipe
s = SMYS (Specified Minimum Yield Strength) of pipe
f = service factor based on testing completed on composite
s_{lt} = 95% lower confidence limit of the long term tensile strength of the composite

As is shown by the equation above, the tensile strength (s_{lt}) is inversely proportional to the calculated thickness of the repair system. So any degradation which occurs due to the higher operating temperatures will only serve to increase the required thickness of the repair system overall. For this reason, the intent for high temperature repairs is to maintain the high tensile strength for the composite material.

In addition to tensile strength, the effect of the elevated temperature on the bonding characteristics of the composite system is equally important; especially due to the nature of the majority of plant applications: leak repairs. The bonding of the repair system is critical for leak repairs in order to maintain an adequate seal to the pipe when subjected to elevated temperatures. Some testing has recently been completed by the Gas Technology Institute on several composite repair systems for the long term testing of the adhesive between layers of composite material, which indicates that there is a certain amount of degradation and loss of strength when fully submerged and subjected to temperatures between 60° to 140° F (15° to 60° C) and can vary significantly from one system to the next.

TESTING OF THE COMPOSITE SYSTEM

Tensile testing was completed at three different stages of the temperature vs. time process in order to determine what effect that extended usage of the material at the elevated temperatures would have on the strength of the system. Once created, two of the three panels were then placed into an oven to be temperature saturated for a period of seven days and for a period of 30 days. All panels were initially cured at room temperature. Prior to testing (but after removal from oven environment), each panel was then cut into the individual tensile coupons using a water jet cutting technique. By using the water jet technology, this creates a cleaner cut with less induced edge stress than using a different cutting method (such as traditional metal saw blades). All coupons were tested on a 10 ksi tensile testing machine to determine tensile strength, tensile modulus, and elongation.

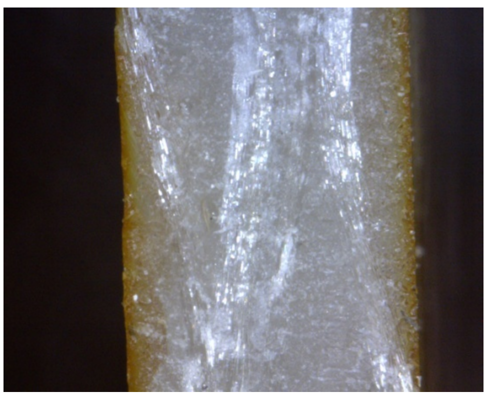

Figure 1: Cross section of coupon

Figure 2: Tensile testing machine

Lap shear testing was also completed at three different stages of the temperature vs. time process in order to determine what effect that extended usage of the material at the elevated temperatures would have on the bonding characteristics of the epoxy system. Lap shear coupons were created to be tested at the same time-temperature intervals as the tensile coupons. Testing was completed on specimens cured at room temperature for 24 hours, after 7 days at 300° F, and after 30 days at 300° F.

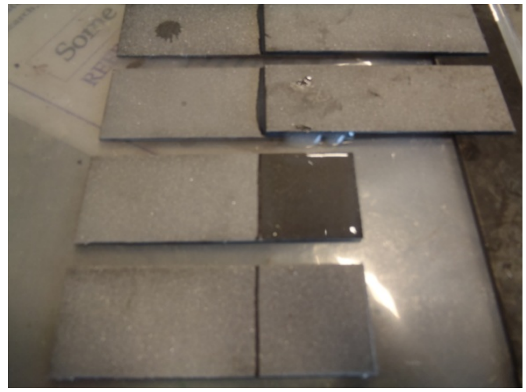

Figure 3: Lap shear sample preparation

Once the coupons had completed the required time-temperature cycle, any excess epoxy on the edges of the overlapped section was gently removed by a wire wheel to remove any additional coverage area of the epoxy. Each coupon was then tested on the same tensile machine as the tensile coupons to determine the lap shear strength of the epoxy system to grit blasted steel.

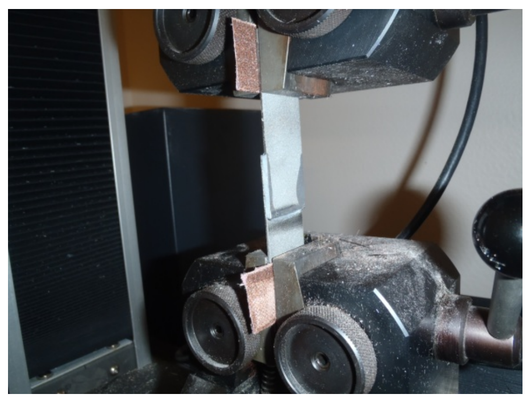

Figure 4: Testing of lap shear sample

Finally, direct pull-off bond testing was completed at three different stages of the temperature vs. time process in order to determine what effect that extended usage of the material at the elevated temperatures would have on the bonding characteristics of the epoxy system and also to determine the percentage of bond strength lost when applied to a damp substrate. Testing was completed on specimens cured at room temperature for 24 hours, after 7 days at 300° F, and after 30 days at 300° F. Each of these time-temperature points had specimens created on a dry surface and a wet surface. The testing was done using standard 20 mm aluminum dollies and a digital pull-off adhesion tester to determine the direct bond strength in each scenario. This testing can serve as a verification of reduction of bond strength by percentage as compared to the lap shear results.

Figure 5: Dolly testing of bonded samples

TEST RESULTS

Tensile Test Results:

As is evident from the Table 1 below, there is no significant loss in strength (approximately 2%) after submersion in the high temperature environment for a period of 30 days. We do see a slight increase in the modulus of the system (approximately 5%) over the time exposed to the high temperature. This testing consisted of submersion in the temperature for the periods of time indicated, then removed and tested at room temperature.

Time	Temp.	Elongation (%)	Modulus (ksi)	Tensile Strength (psi)
24 Hrs	Room Temp.	2.08	4.385	85,800
7 Days	300° F	2.28	4.259	85,400
30 Days	300° F	2.26	4.610	84,500

Table 1: Tensile Testing - Time vs. Temperature

Lap Shear Test Results:

Results from the lap shear testing show a very promising retention of properties. You can see that after 7 days in the high temperature environment, there is no loss of lap shear strength. It is only in the 30 day samples that we begin to see the beginnings of any loss in value. Even with this loss, which is only approximately 20% of the initial value, the end result is almost 5 times stronger than the minimum value as stated in the ASME PCC-2 as the requirement for a composite system. This is of great importance to the intended use of the composite system, as it shows that the material can be used at continuous high temperatures and maintain the lap shear design strengths of the composite.

Time	Temperature	Lap Shear Strength (psi)
24 Hrs	Room Temp.	3,150
7 Days	300° F	3,180
30 Days	300° F	2,493

Table 2: Lap Shear Testing - Time vs. Temperature

Direct Pull-Off Adhesion Results:

The direct pull-off adhesion results are also very promising. There is a definite increase in adhesive properties based on the testing completed to date. The test machine used has a maximum pressure capacity of approximately 3,400 psi, and this value was reached during the adhesion tests being completed. Because there was need to get some usable data on the effect of the temperature, it was decided that the pressure should be cycled from 0 psi to the machine maximum and the number of cycles would be recorded and used in the evaluation process. In addition, by applying to both wet and dry surfaces, we can gauge the effectiveness in "wet" conditions. There is a small effect on the adhesion when applied to wet surface as opposed to when applied to a dry surface, although, this seems to be increased after time in the high temperature as the results after only 7 days are equal to that of the dry specimens. This is further reinforced by the 30 day "wet" results which show only a 7% difference between the same specimen applied to a dry surface. Again, this further confirms that the system will be suitable for sustained usage at these elevated temperatures.

Time	Condition	Temp.	Adhesion (psi)	# Cycles
24 Hrs	Dry	Room Temp.	>3,400	8
7 Days	Dry	300° F	>3,400	>20
30 Days	Dry	300° F	3,354	16
24 Hrs	Wet	Room Temp.	2,635	NA
7 Days	Wet	300° F	>3,400	>20
30 Days	Wet	300° F	3,149	18

Table 3: Direct Pull-off Bond Testing

TESTING DISCUSSION

It should be noted that as the epoxy was "aged" in the high temperature environment, it underwent a color change. This phenomenon is normal and expected as a general characteristic of the system. It should also be noted that the observation was made that the ingress of the color change was limited to the outer edges of the coupons and the interior of the coupon did not seem to be affected, even after the prolonged submersion in the high temperature environment. This leads to a hypothesis that the material has some insulating qualities which protect a large portion of the interior strength of the system. This seems to be supported due to the fact that while the tensile strength shows no significant reduction, the lap shear strength value did slightly decrease.

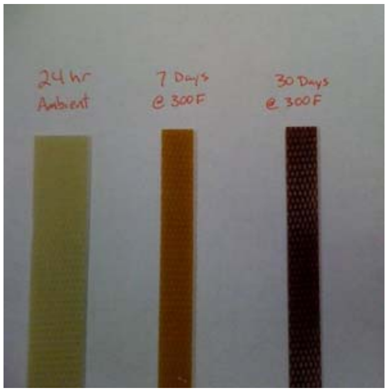

Figure 6: Color change of composite over time under temperature

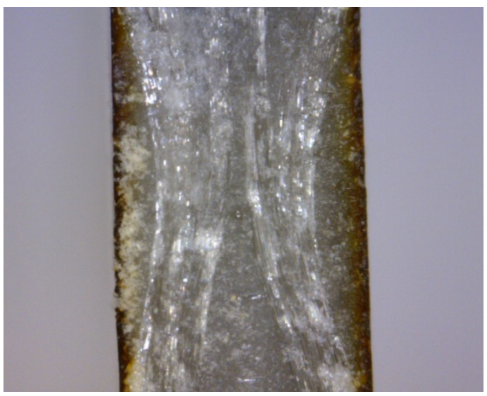

Figure 7: Coupon at 30 days of 300 F with limited color change ingress on coupon

FIELD USE OF THE COMPOSITE SYSTEM

The location of this application case study is a refinery in southeast Texas, having a crude oil processing capacity of 247 MBD. The refinery processes mainly heavy, high-sulfur crude oil, but also processes light, low-sulfur crude oil.

During a routine inspection of process pipelines using Ultrasonic testing, thin spots were discovered on a DMV bypass line in the Sour Crude Unit. The system with the thin spots consisted of a 10” Sch. 40 API 5L Gr. B pipe with an original wall thickness of 0.365”. Inspection of the pipe recorded readings of up to 0.19” remaining thickness, representing an internal wall loss of almost 50%. The product carried in the pipe was top pump around fluid consisting mainly of heavy naphtha and kerosene. The line operates at around 270° F and 215 psi during normal operating conditions, with a design temperature and pressure of 400° F and 280 psi respectively.

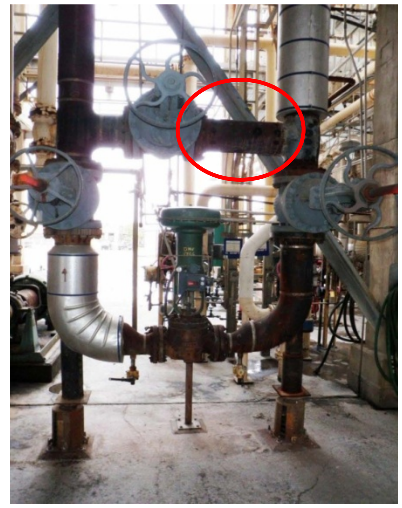

Figure 8: Section of pipe with thinning wall

Due to the inability to repair this line without taking it out of service, which would entail a unit shut down, it was decided to pursue repairing it while in service utilizing either a repair clamp or a composite wrap system to prevent a leak during continued operation. The defect was in a section of pipe approximately 2 feet in length and thus using a repair clamp that size on a 10” line would prove to be very costly and cumbersome. The primary objective in repairing thinning pipe is to restore the structural strength in order to prevent catastrophic failure. Additionally, the repair must be resistant to corrosion from the product in case the pipe does thin to failure. Another factor being considered while deciding the repair form was the relatively high temperature of the line.

Composite wraps were currently being used successfully at this facility, but mostly were in moderate temperature applications. A small number of high temperature composite wrap repairs were performed successfully in the past here, but involved tedious work. This was mostly because of the running of the epoxy at high temperatures due to reduction in viscosity. Personnel involved in such high temperature composite repair applications revealed the difficulty in maintaining the required amount of epoxy to activate the composite wrap. The epoxy would fail to adhere sufficiently to the pipe and/or the underlying layer of wrap, thus requiring the applicators to catch runoff epoxy repeatedly and would end up consuming large quantities of epoxy due to wastage/spillage and having high chance of disbondment between the composite layers, in addition to safety concerns of epoxies which may emit vapor under elevated temperatures.

This refinery has been successfully using composite wrap systems from Neptune Research (NRI) in several different services. The main advantages of using such a repair system are the cost effectiveness and ease of the solution. Compared to making a permanent repair, a composite repair offers to make an effective repair for a fraction of the cost on the run for a determined amount of time until a permanent repair can be made. The high temperature composite repair system from NRI was evaluated to make repairs on the defects on the 10” TPA line. The usability of this system at elevated temperatures in addition to the epoxy system maintaining viscosity at elevated temperatures were factors in choosing this system to make the repair.

After submitting details on the repair job to NRI engineering, it was determined per ASME calculations that 8 layers of wrap would be required to fully restore the structural integrity of the pipe. The repair was performed in cool weather conditions, helping maintain a skin temperature of around 250° F during installation of the wrap system. The line was prepared by grit blasting to a clean, rough surface according to NACE 2 (SA 2.5) standards.

Figure 9: Surface preparation of the pipe section to be repaired

The custom-woven, E-glass fiber wrap system was thoroughly impregnated with the epoxy formula using methods suggested by the manufacturer. Sufficiently long curing time of the epoxy enabled the tape to be wrapped on the pipe in the manner prescribed without gelling too quickly for effective application. Although some small amount of epoxy run off was present, it was not significant, which helped ensure a thorough wet on wet application of the composite layers. After the installation of the composite system, a layer of compression film was used to hold the epoxy formula during curing.

Figure 10: Installation of the composite repair system

A tap test was performed successfully after the system had cured to ensure that no air pockets existed. Additionally, a durometer hardness test was performed a few days after installation to ensure proper resin consistency, curing and hardness. The repair system was visited after a few months to check for any damage. Besides an expected change in color to dark brown, the composite system appeared to retain its integrity.

Figure 11: Measurement of service temp for composite repair

Figure 12: Composite repair after 6 months in service with no failure

Due to a leak further downstream from the site of the composite repair system on the same line, it was decided to use a pipe enclosure to seal off the entire pipe system. Thus, monitoring the integrity of the composite wrap was not possible from that point forward. There are plans to re-examine the repair once the line is replaced in the near future.

CONCLUSION

The increasing use of composite repair systems is being justified more and more due to the many benefits of such a repair system. The ability to make reliable, albeit temporary repairs on damaged pipe systems on the run, without the loss of production is a great advantage. Their usability in a wide spectrum of services, and now temperatures, make them an even more attractive repair option.

With proper testing and validation to ensure proper design characteristics, it is quite possible to make successful and efficient repairs using composite materials on high temperature process pipes. The specific system used should certainly be validated through successful testing of the system at the intended design temperature. But with this information in hand, owner/operator of process facilities can be confident in the ability of composites to be used for repairs.

FUTURE WORK

This testing program and subsequent case study discussed has focused on continuous submersion of the composite in the high temperature environment. It is recommended that the effect of temperature cycling on the properties of this system be examined as well to insure that the change in temperature does not negatively effect these values, or that it is at least a known effect that can be designed for. This phenomenon is quite frequent in the processing environment where temperature changes occur at a high rate on the pipe network.

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REFERENCES

Green, Matthew. "Developing a Composite Repair System for High Temperature Pipe Repairs." American Composites Manufacturers Association (2011)

ASME Post Construction Committee. "ASME PCC-2-2011: Repair of Pressure Equipment and Piping 2011 Edition - Article 4.1." American Society of Mechanical Engineers (2011)

Alexander, Christopher, and B. Francini. "State of the Art Assessment of Composite Systems Used to Repair Transmission Pipelines." IPC2006-10484, Proceedings of the 6th International Pipeline Conference (2006)

D. Germata, K. Stutenberg, and K. Farrag. “Composite Pipe Repair Systems Interim Report: Long-Term Shear Test Results.” Gas Technology Institute, (April 2010)

Jones, Denny A. (1996). “Principles and Prevention of Corrosion.” Second Edition. Prentice Hall, New Jersey.

Koch, Gerhardus H., et al (2002). “Corrosion Costs and Preventative Strategies in the United States.” NACE International. Texas.