

Scientific Investigation of ABF[®] II Steel Pipe in Hybrid Fire Sprinkler Systems

Abstract

The use of ABF[®] II coated steel pipe in hybrid steel/CPVC fire sprinkler systems has been scientifically investigated. Several sites with leaks allegedly caused by ABF II were analyzed and evaluated. The primary cause of the leaks was found to be poor quality CPVC pipe and the next most significant cause was found to be unreasonably high stresses on the CPVC. ABF II was not found to be the primary or driving cause of failures at any of the sites investigated. An intermediate scale fire sprinkler system was constructed and tested to determine the potential for impact of the ABF II coating on performance of CPVC pipe. ABF II coated pipe has at most a mild effect on CPVC pipe and fittings in real-world conditions as quantified by industry-recognized sustained pressure and tensile creep rupture tests. These tests showed that CPVC pipe exposed to ABF II coating in water performed as well as CPVC pipe exposed to other ancillary products that appear on the Lubrizol FGG/BM/CZ[™] compatibility list.

Overview

Allied Tube & Conduit and Tyco Fire Suppression and Building Products previously reported that it became aware of a limited number of sites with failures of chlorinated poly(vinyl chloride) (CPVC) fire sprinkler pipe and fittings. At that time, concerns were raised by some customers that chemical components of the anti-microbial coating from Allied's ABF II coated steel pipe may be causing the leaks. In response, Allied and Tyco assembled a team of scientists and industry experts, working with Lubrizol and customers, to investigate. The team of scientists and industry experts reviewed prior analyses, performed laboratory and intermediate scale experiments, and sought information related to existing installations in order to address customer concerns about the use of Allied ABF II coated sprinkler pipe in mixed steel and CPVC fire sprinkler systems, and to determine whether the ABF II coating was the cause of environmental stress cracking (ESC) failures in CPVC pipe and fittings. Our team has substantially completed its testing and analysis, and as responsible leaders in the fire sprinkler industry, Allied and Tyco want to update the industry and customers on our findings.

This update will first review the site investigations which were conducted on the reported CPVC fire sprinkler pipe and fitting failures arising in hybrid ABF II steel and CPVC fire sprinkler systems and identify prevalent causal and contributing factors. Next, this update will provide an overview of chemical compatibility and environmental stress cracking of CPVC pipe and fittings, identifying the current state-of-the-art. A comprehensive approach to evaluate the performance of ABF II in a hybrid steel-CPVC fire sprinkler system is introduced. An intermediate scale fire sprinkler system similar in design, composition, construction, and operation to the real-world was engineered for detailed analysis and testing. The intermediate scale test system was used to evaluate the long-term interaction of ABF II steel pipe with CPVC fire sprinkler pipe under real world conditions. This update also provides in depth characterization and creep rupture analyses of exposed CPVC materials obtained from the hybrid intermediate scale test system.

Since its introduction, Allied's ABF II anti-microbial coated steel sprinkler pipe has been installed and successfully maintained in millions of feet of steel-CPVC hybrid systems. The number of sites exhibiting CPVC pipe and fitting failures in which concerns about ABF II have been raised represents less than one tenth of one percent of such installed hybrid systems in the Americas. The Allied/Tyco investigation, testing and analysis completed to date fully corroborate this successful performance history.

Site Investigations

Investigation into the origin of CPVC fire sprinkler pipe and fitting failures associated with hybrid fire sprinkler systems containing Allied ABF II coated steel pipe has revealed a variety of different causes for the reported failures. It readily became apparent that the cause of a leak (or a series of leaks) requires a thorough, comprehensive investigation using a scientific and systematic approach. Each failure requires a careful and thorough evaluation of the mechanical and chemical conditions including combinations of these conditions. Furthermore, an analysis of the quality of manufacture of the CPVC pipe and fittings and the impact of the installation conditions and operating environment must be considered. Additionally, where there are a variety of chemicals present in a system, both the nature and amounts of each chemical must be considered. There is usually no single, simple explanation for all leaks in a fire sprinkler system. Instead, each failure must be evaluated uniquely relative to the mechanical, chemical, and material aspects surrounding that failure.

The investigation revealed that the primary cause of CPVC leaks at the sites investigated was poor quality CPVC pipe. Although CPVC manufacturers seek to produce high quality product, on occasion, quality problems do occur as a result of manufacturing deficiencies. The investigation uncovered distinctive and measurable quality problems with some CPVC pipe from one manufacturer that was produced through the mid-2008 time frame. In many instances, the cracked pipe segments exhibited visible defects, including external score lines, internal score lines, burn lines, and internal surface irregularities. Additionally, the fractures were cracks or splits along longitudinal lines in the manufacturing extrusion direction. These manufacturing quality defects were the main cause of the CPVC pipe failures found in the investigation of CPVC leaks.

Not all CPVC pipe and fittings are made to the same performance specifications. Different manufacturers may use different chlorinated poly (vinyl chloride) polymers, different additive packages in the formulation, and different quality control procedures. There are minimum requirements that all manufacturers are expected to meet based on applicable standards.^{1,2} BlazeMaster® requirements established by Lubrizol exceed those minimum industry requirements. In addition, under standard industry testing, Tyco's BlazeMaster CPVC pipe substantially outperforms the other manufacturer's (non-BlazeMaster, pre mid-2008) CPVC pipe. Comparative testing has shown that BlazeMaster CPVC pipe performs more than 5 times longer than that other manufacturer's CPVC pipe when subjected to high mechanical stress. Compared to CPVC pipe with visible manufacturing quality defects, BlazeMaster CPVC pipe performs nearly 10 times longer than the other manufacturer's CPVC pipe. Clearly, manufacturing quality is critical when selecting CPVC pipe and fittings.

Another significant cause of CPVC leaks is high mechanical stress. These failures include those due to overpressure in the system (pressure surges, water freezing, etc.), mechanical impact, and ESC where the magnitude of the mechanical stress is the significant contributor. ESC of CPVC is caused by a combination of mechanical stress and a chemical agent over time. Failures involving ESC typically involved an unusually high mechanical stress level applied to the CPVC which may arise from factors such as poor installation techniques and use of improper or poorly designed pipe hangers. The chemical agent in ESC-related failures is commonly introduced through the use of inappropriate ancillary materials within the sprinkler system (e.g. certain cutting oils, thread sealants, and gasket lubricants) or introduced externally by other construction trades (e.g. fire caulks, wiring insulation, insecticides). Such agents act in combination with high applied stress levels on the CPVC pipe or fitting. Awareness through education and training of fire sprinkler system contractors, other building and trade contractors, and building owners/property managers is an essential component to the successful installation and continued service of CPVC in any fire sprinkler system.

The investigation also revealed that another common cause of CPVC leaks is poor installation practices. For example, cement drips are formed when an excessive amount of solvent cement is applied, and these cement drips can cause a decrease in the overall strength of the pipe. The investigative team also found CPVC leaks were caused in part due to unreasonably high mechanical stresses in pipe and fittings caused by excessive bending and manipulation during installation and/or service life. Fire sprinkler system installation contractors must follow applicable standards and guidelines for installation, use approved/listed materials appropriate for the application, and conform to the manufacturer's installation instructions and guidelines. Fire sprinkler contractors must also ensure that their crews are adequately trained to properly handle CPVC installations.

Evaluation of Chemical Compatibility

Compatibility is a term that is used throughout scientific and engineering communities with broad implications. However, there is currently no universally accepted definition for "compatibility" of chemicals or products with CPVC pipe and fittings in fire sprinkler systems. Although the concept of compatibility is often discussed, it is clear that different people and organizations have different perspectives on what "compatibility" and "incompatibility" mean.

One of the most widely recognized programs for assessing compatibility is the Lubrizol FGG/BM/CZ™ System Compatible program.³ Products may be submitted by their manufacturer to this program for analysis and testing. This is a proprietary testing program and the details of the testing and analysis are not publicly available. However, it is believed to include an evaluation of the chemical composition of the product, laboratory testing, an audit of the manufacturing process, and a contractual agreement between the product manufacturer and Lubrizol. It is important to note that the Lubrizol compatibility program applies only to Lubrizol's family of CPVC piping products, including BlazeMaster® fire sprinkler pipe and fittings, and that "Other manufacturers and/or brands of CPVC piping products are not eligible and do not comply with this program."³ Lubrizol publishes on its web site lists of compatible products and incompatible products. However, these lists are not all-inclusive and a large

number of products that are commonly used in the construction of fire sprinkler systems are on neither list. Also, many products that appear on Lubrizol's compatible list produce a measurable reduction in CPVC performance. Thus, Lubrizol's requirements for inclusion of a product on the compatibility list allow for some reasonable reduction in CPVC performance.

FM Global has recently proposed a test specifically for compatibility of steel pipe with antimicrobial or antibacterial coatings/films with CPVC components of fire sprinkler systems.⁴ The proposed standard outlines the required tests and pass/fail criteria in detail. This laboratory testing program loosely follows some of the methods outlined in ASTM D543 "Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents." This testing program explicitly allows for some reduction in CPVC performance when exposed to a water wash from the interior of the steel pipe.

Underwriters Laboratories Inc. (UL) is in the process of developing a comprehensive standard for the compatibility of ancillary products with CPVC, including antimicrobial or antibacterial coatings inside steel pipes. Key elements of the process include definition of the scope of the standard, selection of test methods, and definition of a standardized CPVC material for testing.

Some in the industry have expressed the opinion that compatibility means "zero tolerance" for any reduction in CPVC performance upon exposure to a product or chemical. In other words, any product or chemical that could be shown in the laboratory to reduce the performance of CPVC upon direct contact would necessarily be classified as "incompatible" with CPVC. However, this is a naïve and infeasible approach in light of the practical realities of constructing a fire sprinkler system. This approach ignores the fact that the product is being used in a fire sprinkler system where some introduction of ancillary products is unavoidable and instead relies upon laboratory experiments that may not be reasonably representative of real-world conditions. There are numerous ancillary products that have been successfully used in CPVC fire sprinkler systems for many years; however, only a handful of these have no impact on CPVC when tested by direct contact in the laboratory. Both Lubrizol and FM Global recognize this aspect and have testing programs that do not require "zero tolerance."

The Allied/Tyco expert team has recently become aware that some investigators are using unrealistic laboratory tests that distort and misrepresent the characteristics and properties of ABF II. Many of these tests were conducted under conditions not reasonably representative of real-world conditions in fire sprinkler systems. Some experiments have even utilized chemicals purported to be similar to ABF II but are, in fact, unrelated to ABF II. These investigators also advocate that ABF II causes chemical degradation (dehydrochlorination) of CPVC (which, if it occurs, can lead to failure), but the experimental method used and data collected do not support this conclusion. More comprehensive testing and analysis demonstrates that some CPVC pipe manufactured prior to mid-2008 by a certain (non-BlazeMaster) manufacturer suffered from unusually high levels of pre-existing chemical degradation caused during their manufacturing process, which is especially evident in samples of CPVC pipe with visible manufacturing quality defects. It has also been suggested that CPVC surface discoloration in samples removed from the field is proof of an ABF II attack on CPVC, but this suggestion fails to account for the myriad of diverse potential sources of visual discoloration of CPVC surfaces—the most obvious

being rust and dirt, both commonly present in fire sprinkler systems and found in systems with or without ABF II coated steel pipe.

Intermediate Scale Test

In order to determine the potential for impact of the ABF II coating on performance of CPVC the expert team constructed, operated, and tested an intermediate scale hybrid steel-CPVC fire sprinkler system. This approach focused on representing real-world fire sprinkler systems rather than conducting laboratory experiments that cannot be correlated to real-world conditions and often use unrealistic chemical exposure conditions. This approach by-passes the challenges and uncertainties associated with laboratory tests of “compatibility.” The scientific investigation included the construction and operation of an intermediate scale steel-CPVC fire sprinkler system including Allied ABF II coated pipe and Tyco BlazeMaster CPVC pipe and fittings representative of real-world fire sprinkler systems. The system and its operation were specifically designed to evaluate the effects of the ABF II coating on CPVC under conditions where the ABF II is transported naturally by the filling process of the sprinkler system, as is the case in real-world applications.

The intermediate scale test provides a thorough and comprehensive investigation of water flow and chemical transport in a system representative of real-world fire sprinkler systems. Furthermore, it includes long-term testing to assess effects on the service life of CPVC pipe and fittings. Thus, this testing has required substantial resources, time, and effort. The result of this effort is a realistic test platform based upon engineering and science fundamentals that encompasses the entire fire sprinkler system as well as its individual components. This comprehensive approach is in sharp contrast to other testing approaches that are much more narrow and which may not be reasonably representative of real-world systems.

The physical configuration of the system is illustrated schematically in Figure 1 below and a photograph is given in Figure 2. It consists of a large water reservoir and booster pump that feeds a hybrid steel-CPVC fire sprinkler system consisting of a 12 foot long 2 inch diameter schedule 40 steel ABF II –coated riser, followed by 15 additional feet of 2 inch diameter steel schedule 40 ABF II-coated horizontal feed main that tees into two mirrored sides (A and B) of the system. Downstream of the ABF II-coated steel mains are 2 inch diameter Tyco BlazeMaster CPVC crossmains, and sprig ups that feed a series of 1 inch diameter branch lines terminating in sprinkler drops. Some sections of the branch lines are constructed of clear PVC to allow for visual observations of the transport process. Each branch line is isolated from the crossmain by a ball valve to allow for containment and sampling of transported materials in each branch line.

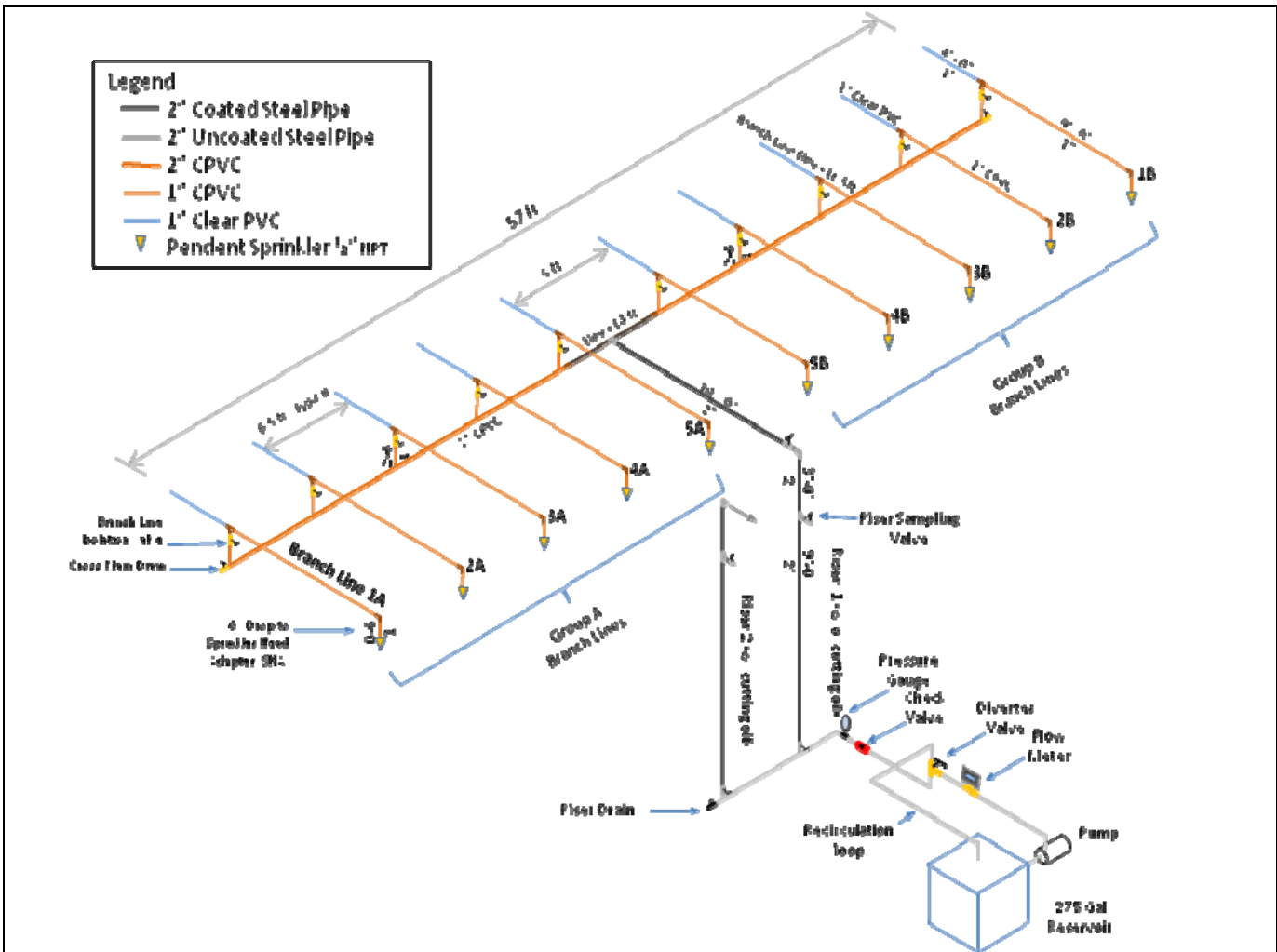


Figure 1. Schematic of the intermediate scale test configuration.



Figure 2. Photograph of a portion of the intermediate scale system, including the reservoir, pump, riser, and crossmains.

All ABF II-coated pipe and CPVC products were obtained from standard commercial stock. This physical configuration considered geometry, proportions (ratio of coated steel to system volume), system size (approximately 20 gallons), and flow conditions of real-world systems and was designed to model typical fire sprinkler systems filled through upstream ABF II coated sections. The engineered design allows for systematic study of water transport phenomena in real-world fire sprinkler systems including the potential for chemicals to be removed from the steel portion of the system, transported downstream to the CPVC portion of the system, and deposited in the CPVC piping.

The geometry and overall size of the intermediate scale system were selected both to provide a fair representation of real-world systems and to enable detailed study and analysis of transport effects during the installation and service life of a fire sprinkler system. Certain aspects of the intermediate scale system, such as the geometry, were simplified to provide greater scientific value of the experiment. While the linear crossmain configuration facilitates tracking, isolation, and sampling of transported chemicals, the geometry is relatively conservative compared to the real-world in that typical systems have greater length and have a significant number of directional changes and fittings, all of which increase turbulent mixing and effective dilution.

The basis for the proportions of coated steel to CPVC components of the intermediate scale system was a survey of existing real-world hybrid sprinkler systems. In general, a sprinkler

system with a higher coated steel surface area to CPVC volume ratio potentially has more available ABF II coating mass per CPVC unit volume, or greater potential concentration. Based on this parameter and the sampled population of systems, the design of the intermediate scale system is conservative, with a ratio of ABF II steel surface area to CPVC system volume that is approximately 30% greater than the average of the surveyed sprinkler systems.

The intermediate scale system was operated to simulate the initial set up and filling of real-world hybrid steel ABF II / CPVC sprinkler systems. The entire system was filled through the as-received ABF II coated steel piping using a controlled velocity, held at elevated pressure for 24 hours, and then drained. The mirrored design of the intermediate scale branch lines allowed for partial sampling at select intervals during the experiments. Half of the 1 inch diameter CPVC branch lines (the A side) were then removed for testing and analysis. These samples thus represent potential exposure of the CPVC pipe to chemicals during the initial fill of the system, which occurs during initial acceptance testing (i.e. hydrostatic pressure testing). The removed branch lines from side A were then replaced (with new CPVC branch lines to maintain the symmetry of the overall system) and the entire system was filled again through the same coated steel piping. After the second filling the system was allowed to sit statically at a nominal system pressure of approximately 150 psi for a number of weeks. The branch lines (both sides A and B) were then removed on a staggered schedule and submitted for testing and analysis. These additional samples thus represent potential exposure of the CPVC pipe to chemicals after the sprinkler system is filled and placed into service sitting stagnant for an extended period of time.

The effect of cutting oils in combination with ABF II coated steel in fire sprinkler systems was also explored. Parallel tests of the intermediate scale system were conducted in order to evaluate possible interaction between the ABF II coating and cutting oil. In the first full run of the system no cutting oils were present. In the second full run of the system, 0.5 mL of FPPI ThreadFit cutting oil was deliberately introduced into each coated steel pipe near the joints to simulate an installation containing threaded steel pipe connections and potential interactions between cutting oil and ABF II on transport behavior – i.e. removal of chemicals from the steel portion of the system, transport to the CPVC portion of the system, and deposition in the downstream CPVC piping.

Water samples from each branch line of both intermediate scale tests were chemically analyzed. Coating materials and cutting oil (in the test where used) were found in the branch lines in varied amounts. The amounts of organic chemicals found were in the concentration range of 2 to 56 ppm (parts per million). [For comparison purposes, this is less than the typical residue content found in municipal tap water.](#) The highest concentrations of chemicals were found in the end-of-line branch lines while only trace amounts were found in most other branch lines. Transport of the chemicals from the upstream steel pipes downstream to the CPVC sections by charging the system with water affects the distribution and concentration of coating chemicals. In the filling of real-world fire sprinkler systems, the effect of turbulent mixing, which is driven by eddy motion of the moving body of water inside the pipes effectively dilutes the concentration of chemicals carried downstream. The simplistic layout of the intermediate scale creates a muted response of turbulent mixing compared to real world systems.

Mechanical performance of CPVC pipe samples exposed to ABF II in the intermediate scale experiment was tested under sustained internal hydrostatic pressure. CPVC samples from branch lines of the intermediate scale experiments both with and without cutting oil were subjected to the sustained pressure testing according to sections 6.2 and 8.4 of ASTM F442 “Standard Specification for Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Pipe (SDR-PR).” The test pressure of 670 psi was applied for 1000 hours, as specified in this standard. This is the same industry-recognized sustained pressure testing required of new, never installed CPVC fire sprinkler pipe. All tested samples held the specified pressure for the entire 1000 hour test duration and passed the ASTM F442 test. Furthermore, the exposure histories of the A and B sides resulted in identical passing performance. All samples were exposed to ABF II in the hybrid steel/CPVC intermediate scale test, both with and without cutting oil present, and passed the same sustained pressure test required of new CPVC pipe that has never been installed.

Mechanical performance of CPVC pipe samples exposed to ABF II in the intermediate scale experiment was also tested by tensile creep rupture. Tensile creep rupture is a widely recognized method for predicting the service life of plastics under stress and for quantifying the influence of chemicals on plastic materials.⁵⁻⁷ Testing involves application of a constant tensile load to a sample and measurement of the time required for the sample to fail (break). High tensile loads (corresponding to high mechanical stresses) result in failures at short times, while low tensile loads (corresponding to low mechanical stresses) results in failures at long times. Tensile creep rupture testing was focused on three different types of samples:

- Control samples: CPVC pipe samples that were not exposed in the intermediate scale experiment, tested by creep rupture in air or immersed in deionized water.
- Samples tested by creep rupture in air.
- Samples tested by creep rupture while immersed in branchline water.

Control samples of CPVC pipe from the same lots used to construct the intermediate scale system were tested to determine baseline performance under unexposed conditions. Some specimens were tested in air and some were tested while immersed in deionized water. The results are shown in Figure 3 below. The data are well represented by a straight line on a log-log plot. There was no significant difference between specimens tested in air and specimens tested in deionized water. These results are consistent with the scientific literature concerning creep rupture testing of engineering plastics and with the performance requirements for CPVC piping used in fire sprinkler systems. The results shown in Figure 3 for the unexposed control samples provide the baseline for evaluation of potential exposure to ABF II in the intermediate scale experiment.

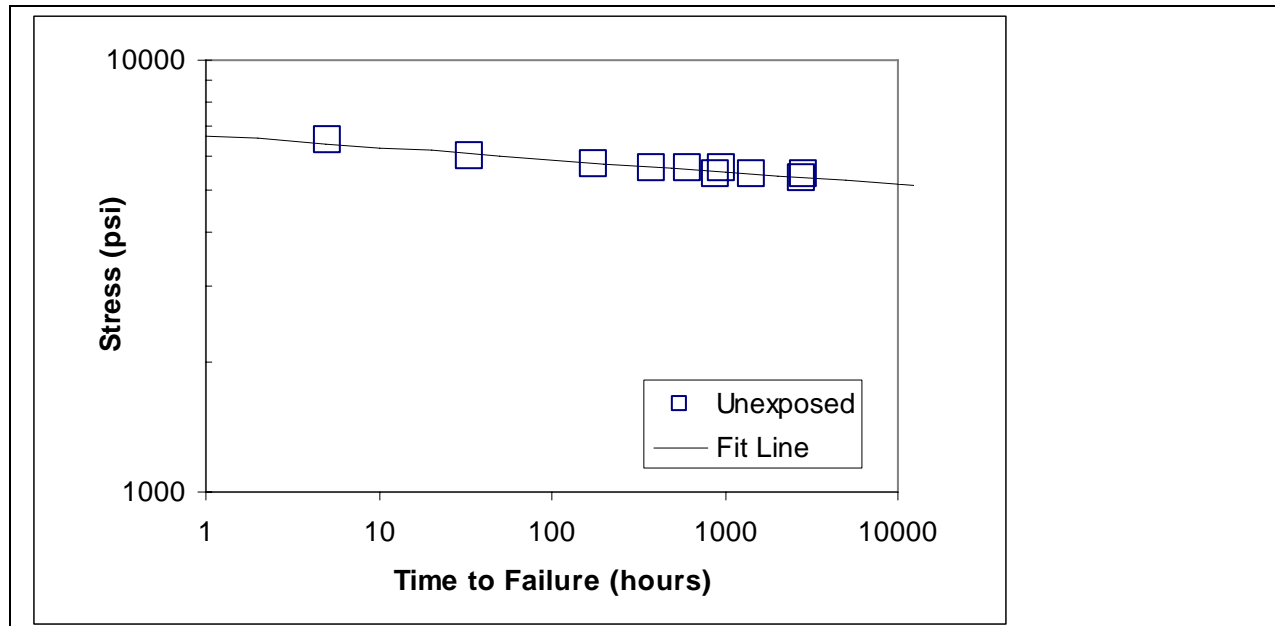


Figure 3. Creep rupture testing of unexposed control samples.

Samples of CPVC pipe from the intermediate scale branch lines 1A and 1B both with and without cutting oil were tested by tensile creep rupture in air. The end-of-line branch line “1” was selected for testing because it represented the worst case scenario from the intermediate scale configuration, the branch line where the highest concentrations of chemicals were found after exposure. Branch lines “A” represent exposure during initial fill of the system while branch lines “B” represent exposure during the initial fill, the subsequent fill, and contact with stagnant water for long periods of time. The closed symbols in Figure 4 below show the results in comparison with the control baseline. The specimens that had been exposed to ABF II performed just as long as the unexposed specimens when subjected to the same levels of mechanical stress. Under these test conditions the performance of the exposed CPVC pipe was indistinguishable from that of new, never installed CPVC control samples.

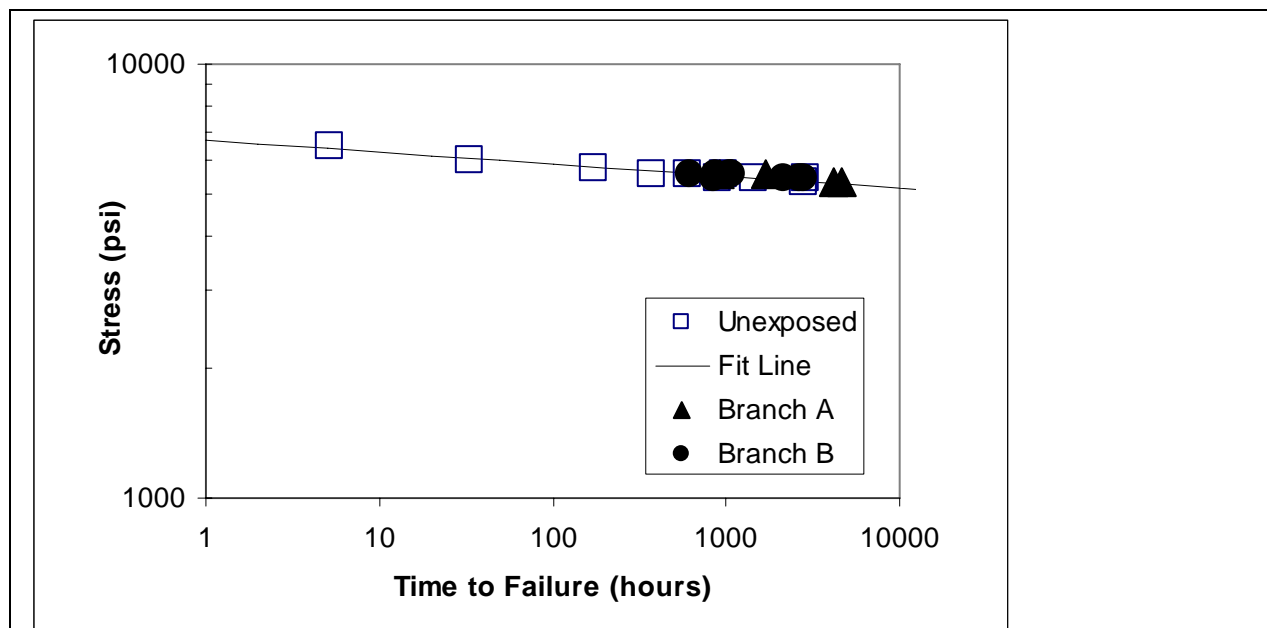


Figure 4. Creep rupture testing in air of branch line samples from the intermediate scale experiment.

Samples of CPVC pipe from the intermediate scale branch line 1B both with and without cutting oil were tested by tensile creep rupture while immersed in water from the same branch line. This experimental protocol utilizes a CPVC specimen exposure somewhat more aggressive than real-world conditions. The end-of-line branch line “1” was selected for testing because it represented the worst case scenario from the intermediate scale configuration, the branch line where the highest concentrations of chemicals were found after exposure. Branch lines “B” represent exposure during the initial fill, the subsequent fill, and contact with stagnant water for long periods of time. Immersion in water from the same branch line during tensile creep rupture testing provides somewhat aggressive exposure because the specimens are exposed to the branch line water on all four sides during testing, rather than only on the inside, which is the real-world condition.

The closed symbols in Figure 5 below show the available results for the “wet” samples in comparison with the control baseline. Testing of additional specimens at lower tensile stresses is ongoing. The data from the “wet” samples, at this point comprising ten individual data points, are well represented by a straight line on the log-log plot. The CPVC branch line samples tested in water from the same branch line show a slight reduction in long-term performance, indicating a mild detrimental effect of exposure. This reduction in performance is significantly less than the reduction observed when other commonly used ancillary products are tested in contact with CPVC. The performance of the “wet” samples as represented by the extrapolated fit line is also only slightly lower than that required of new, never installed CPVC sprinkler pipe. The design of these systems includes a “service design factor” (safety factor) “which takes into

consideration all the variables and degree of safety involved in a thermoplastic pressure piping installation.”^{8,9} The long-term extrapolated (to 100,000 hours) “wet” sample results represent a change of only 10% in the prescribed service design factor.

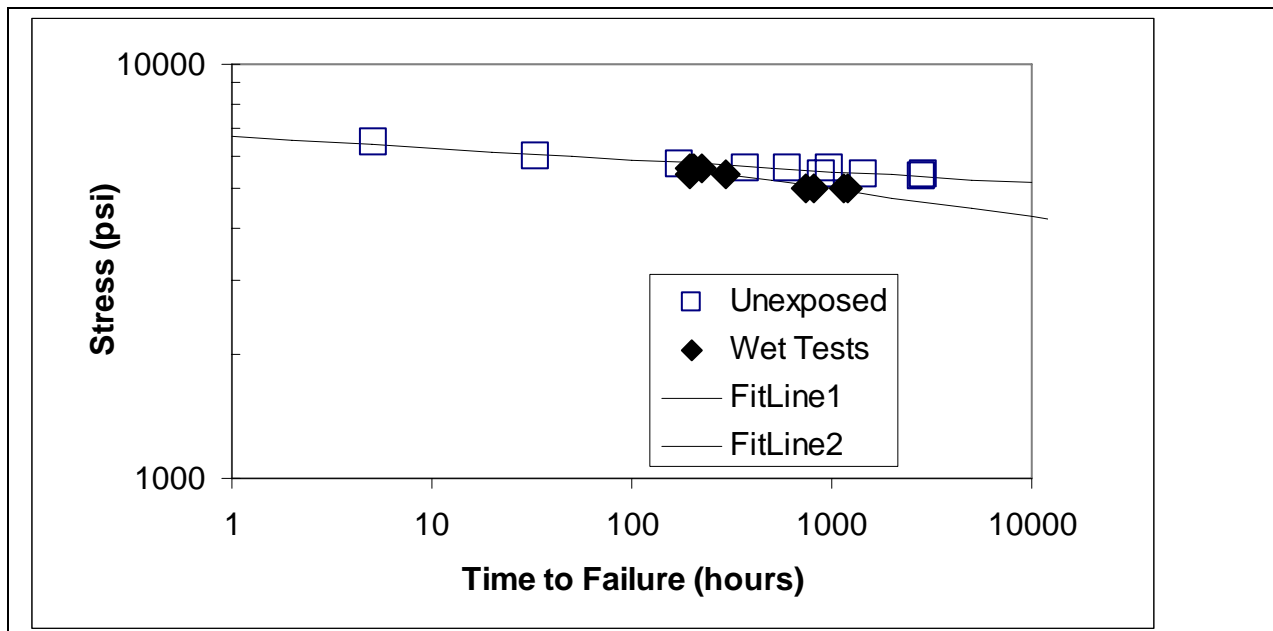


Figure 5. Creep rupture testing in branch line water of branch line samples from the intermediate scale experiment.

Typical mechanical stresses in a fire sprinkler system include the system operating pressure, gravity forces on the water-filled pipe, slight bending of the pipe, and contact forces at hangers. The magnitudes of these stresses are generally less than 2,000 psi in appropriately installed systems. As with many other ancillary products, including some products that are on the Lubrizol compatibility list, ABF II has a mild effect that slightly reduces the CPVC performance. However, in an appropriately installed system the levels of mechanical stress are far below the levels where the slight reduction in CPVC performance would influence the anticipated system lifetime.

Conclusions

The use of ABF® II coated steel pipe in hybrid steel/CPVC fire sprinkler systems has been investigated by a team of scientists and experts. Investigation of leaks in hybrid ABF II steel/CPVC systems has revealed a variety of different causes for the CPVC leaks. However, ABF II was not found to be the primary or driving cause of failures at any of the sites investigated. An intermediate scale fire sprinkler system representative of real-world systems was constructed and tested to determine the potential for impact of the ABF II coating on performance of CPVC. When a sprinkler system is filled through the upstream ABF II coated steel sections coating materials are carried downstream and may be transported in to the CPVC portion of the system. The transport mechanism is an important factor in real-world systems that

effectively dilutes water borne chemicals but is not considered in many laboratory tests. ABF II coated pipe has at most a mild effect on CPVC pipe and fittings in real-world conditions as quantified by industry recognized sustained pressure and tensile creep rupture tests. The results of this investigation help explain why the overwhelming majority of installations of ABF II coated steel pipe with CPVC pipe and fittings in appropriate, real-world, combined steel-CPVC fire sprinkler systems have provided reliable service without incident for many years.

References

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For additional information or questions, visit www.alliedtube-sprinkler.com/cpvc or contact Allied/Tyco at 1-888-890-2278 in the United States or at 1-708-339-1610, extension 7301 outside the United States.