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Report

Project 05-1059

Final Report

Proposal for the Evaluation of the Chlorine Resistance of UV Exposed PEX Pipe

Confidential

Executive Summary

The purpose of this project was to examine ASTM F2023 and NSF P171 Protocol data sets to develop a test and analysis protocol to assess whether a significant change in chlorine resistance test performance of a PEX pipe sample occurs following UV exposure.

The test and analysis protocol would have simple criteria by which a UV exposed sample could be compared to existing data or to an unexposed sample and a declaration made as to whether a significant difference is observed. This report outlines the proposed methodology and details the approach that led to the methodology.

The proposed method is:

1. Chlorine resistance testing, in general accordance with the ASTM F2023 test method, at 115 °C and 60 psig:
   - 5 UV exposed specimens
   - 5 unexposed specimens of the same sample lot or use the Expected Failure Time from a data set in accordance with ASTM F2023
2. Visually confirm that the failures are all Stage III brittle oxidative failures. If mixed-mode or Stage II failures are observed, testing at a different test condition shall be performed to ensure Stage III failures.
3. Calculate the average failure time for the UV exposed specimens $\left(\bar{x}_{\text{UV Exposed}}\right)$.
4. Calculate the average failure time for the unexposed specimens $\left(\bar{x}_{\text{Unexposed}}\right)$.
5. Calculate the % Decrease in Failure Time of the UV exposed specimens relative to the unexposed specimens:

$$\%\ \textit{Decrease in Failure Time} = \left(1 - \frac{\bar{x}_{\text{UV Exposed}}}{\bar{x}_{\text{Unexposed}}}\right) \cdot 100\%$$

6. If the *% Decrease in Failure Time* is equal to or less than the *Maximum Allowable Decrease in Failure Time* of 21%, the UV exposed sample passes the requirement and is not considered to be significantly different in chlorine resistance test performance to the unexposed sample.
   If the *% Decrease in Failure Time* is greater than 21%, the UV exposed sample does not meet the requirement and is considered to be significantly different in chlorine resistance test performance to the unexposed sample.
   If the value for the *% Decrease in Failure Time* is negative, the UV exposed sample passes the requirement and is not considered to be significantly different in chlorine resistance test performance to the unexposed sample.
7. Alternatively to the above methodology, a UV exposed sample could be tested and analyzed in accordance with ASTM F2023 (full data set). A result meeting the requirements of ASTM F876 would indicate that the chlorine resistance performance of the UV exposed pipe sample is acceptable.

This report provides the basis for: 1. the analysis method and the criteria for the *Maximum Allowable % Decrease in Failure Time* of 21% and 2. the number of data points to test. The approach was to examine the typical variability in the regression data sets and to choose a representative number that characterizes the variability. The chosen measure of variability was the 95% (two-sided) Lower Prediction Limit relative to the regression mean expected value of a full data set. This was called the LPL ratio. The LPL ratio was calculated across a range of test stresses and three temperatures for eight supplied data sets and averaged. The results were quite consistent at 21% with a standard deviation of 5%. This value represents the average of the differences in the LPL failure times that could be observed in repeat testing that would not be considered to be statistically different. Five specimens per sample were chosen to provide a reliable mean test failure time for comparison purposes.

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Report No.: Project 05-1059 – Final Report

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Date of Issue: August 18, 2005

Purpose of Test:

The purpose of this project was to examine ASTM F2023 and NSF P171 Protocol data sets to develop a test and analysis protocol to assess whether a significant change in chlorine resistance test performance of a PEX pipe sample occurs following UV exposure.

The test and analysis protocol would have simple criteria by which a UV exposed sample could be compared to existing data or to an unexposed sample and a declaration made as to whether a significant difference is observed. This report outlines the proposed methodology and details the approach that led to the methodology.

Test Item Identification and Description:

Analysis was performed using a total of eight ASTM F2023 or NSF P171 Protocol data sets provided by the members of the PPI High Temperature Division. Details of the different data sets have not been included in the report in order to keep all of the data confidential.

Test Methodology:

The approach to the analysis was to examine the typical variability in the regression data sets and to choose a representative number that characterizes the variability. The chosen measure of variability was the 95% (two-sided) Lower Prediction Limit (LPL) relative to the regression mean expected value (known as the Expected Failure Time or EFT) of a full data set. This was called the LPL ratio.

The 3 parameter Rate Process Model was used to calculate the LPL ratios over a range of test stresses and three temperatures for the supplied data sets. A commercial statistical analysis computer package was used to perform the analysis. The *% Decrease in Failure Time* was defined as the % decrease in failure represented by the LPL ratio and was calculated as follows:

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$$\%\ Decrease\ in\ Failure\ Time = \left(1 - \frac{95\%\ LPL}{EFT}\right) \cdot 100\% = \left(1 - LPL\ ratio\right) \cdot 100\%$$

where the 95% LPL and the EFT are in hours.

The *% Decrease in Failure Time* was calculated at three stress levels at three test temperatures for each of the eight data sets. The values were averaged and the *Maximum Allowable % Decrease in Failure Time* defined. This value represents the average of the differences in failure times that could be observed in repeat testing that would not be considered to be statistically different.

This value will serve two purposes:

1. If an ASTM F2023 data set is available for a sample, a comparison to the data set can be made with additional testing of a number of UV exposed specimens.

OR

2. If an ASTM F2023 data set is not available for a sample, a data set comparison can be made between the UV exposed and unexposed samples by testing a number of specimens of each sample at a single chlorine resistance test condition. A full data set would not be required.

Test Results and Analysis:

Determination of the Value for the Maximum Allowable % Decrease

Table 1 provides a summary of the *% Decrease in Failure Time* averaged for each temperature of each data set. The data sets are listed from the data set with the smallest average % decrease to the highest. A summary of the range in values (an indication as to the variability between stresses) observed for each data set at each temperature is provided in Appendix A.

Table 1: Summary of the Average *% Decrease in Failure Times* at Three Temperatures

Data Set	Average % Decrease in Failure Times		
	115 °C	**105 °C**	**95 °C**
A	14	13	15
B	16	16	17
C	21	20	21
D	21	20	21
E	21	21	23
F	23	22	23
G	23	23	25
H	31	30	32
Mean	*21*	*21*	*22*
Standard Deviation	*5*	*5*	*5*
Overall Mean	*21*		
Overall Standard Deviation	*5*		

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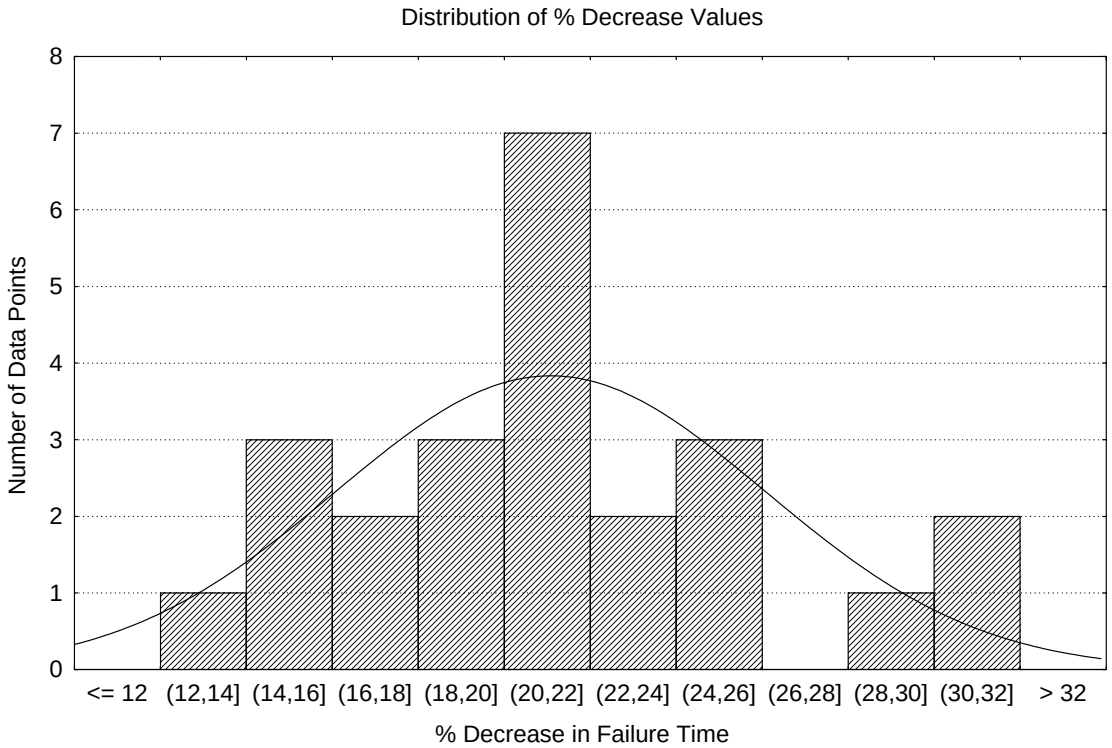
The values in the average % decrease in failure time range from 13 to 32%. The range is likely a result of different levels of variation within each data set. This variation is a result of sample variation, test parameter variability (within the control limits of the methodology) and unknown uncontrolled parameters. However, the majority of the data sets (five out of the eight data sets) have values that fall in the 20 to 25% range.

Between temperatures, there appears to be minimal differences in the average values for each data set. This is reflected in the mean value for all of the data sets at each of the three temperature conditions which are also very similar (21 to 22%).

The overall mean value from all of the data was calculated to be 21% with a standard deviation of 5%. As shown in Figure 1, the overall distribution of the data appears to be a normal distribution. If it is assumed that the data sets examined are representative of the general population, then the value of 21% is a good representation of the average % decrease of the population.

Therefore, the Maximum Allowable Decrease in Failure Time is proposed to be 21%. This value represents the average of the differences in the LPL failure times that could be observed in repeat testing that would not be considered to be statistically different.

Figure 1: Distribution Plot of the % Decrease in Failure Time Values



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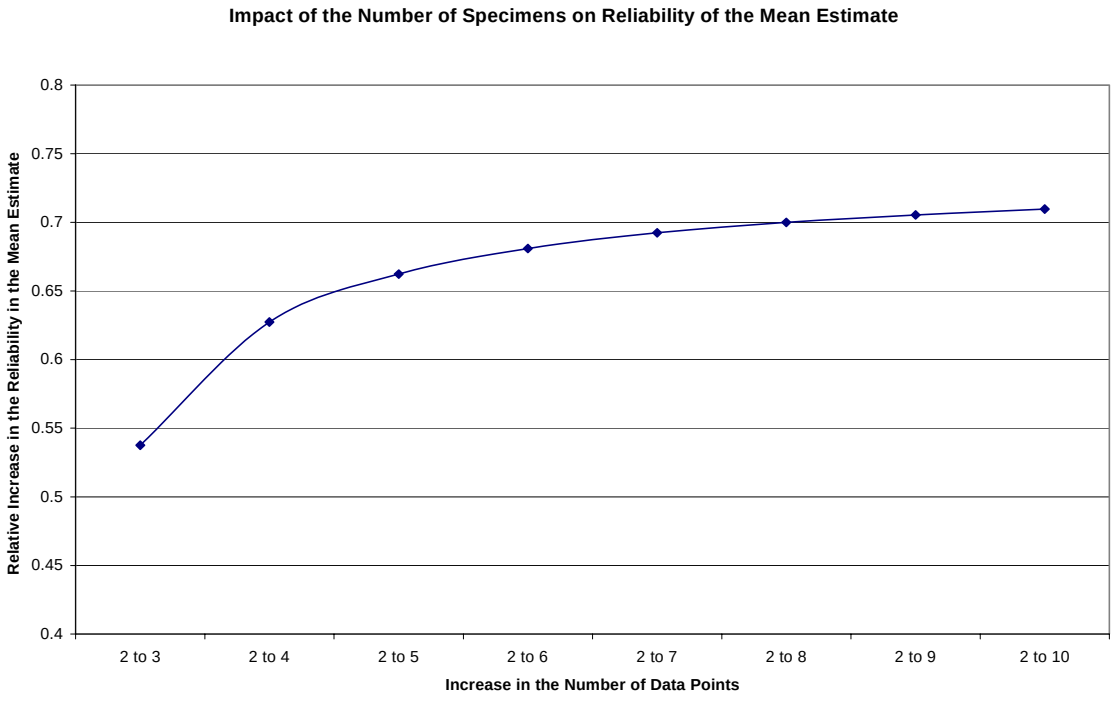
Determination of the Minimum Number of Data Points for the Analysis

In determining the number of specimens that should be tested for the unexposed sample and the UV exposed sample, several factors were considered. The higher the number of specimens, the better the resolution and the lower the uncertainty in the estimated mean failure time. However, it is not feasible or realistic to test an infinite number of specimens. Therefore, the optimal number of specimens to test was examined. As a basis for the analysis, the impact of incremental numbers of additional data points on the reliability of the mean value was calculated. Figure 2 depicts how the use of 3 to 5 data points can improve the reliability of the mean value. The largest improvements occur from 2 to 3, 3 to 4 and 4 to 5 data points. The addition of one or two specimens would improve the reliability of the mean calculated values by 9 or 3%, respectively, compared to three data points. Beyond five specimens, the improvement in the reliability is less than 2% for each additional specimen. Therefore, it is recommended that a minimum of five specimens of each sample, UV exposed and unexposed, be tested for reliable mean failure times for comparison purposes.

Appendix B provides additional information used in the approach for the analysis.

Figure 2: The % Improvement on the Confidence of the Mean with Increasing Data Points



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Proposed Procedure:

Based on the analysis performed, the following procedure is proposed to assess whether a significant change is observed in chlorine resistance test performance of UV exposed PEX pipe samples:

1. Chlorine resistance testing, in general accordance with the ASTM F2023 test method, at 115 °C and 60 psig[a]:
   - 5 UV exposed specimens
   - 5 unexposed specimens of the same sample lot or use the Expected Failure Time from a data set in accordance with ASTM F2023[b]
2. Visually confirm that the failures are all Stage III brittle oxidative failures. If mixed-mode or Stage II failures are observed, testing at a different test condition shall be performed to ensure Stage III failures.
3. Calculate the average failure time for the UV exposed specimens $\left(\bar{x}_{\text{UV Exposed}}\right)^{c}$.
4. Calculate the average failure time for the unexposed specimens $\left(\bar{x}_{\text{Unexposed}}\right)^{c}$.
5. Calculate the % Decrease in Failure Time of the UV exposed specimens relative to the unexposed specimens:

$$\%\ \textit{Decrease in Failure Time} = \left(1 - \frac{\bar{x}_{\text{UV Exposed}}}{\bar{x}_{\text{Unexposed}}}\right) \cdot 100\%$$

6. If the *% Decrease in Failure Time* is equal to or less than the *Maximum Allowable Decrease in Failure Time* of 21%, the UV exposed sample passes the requirement and is not considered to be significantly different in chlorine resistance test performance to the unexposed sample.
   If the *% Decrease in Failure Time* is greater than 21%, the UV exposed sample does not meet the requirement and is considered to be significantly different in chlorine resistance test performance to the unexposed sample.
   If the value for the *% Decrease in Failure Time* is negative, the UV exposed sample passes the requirement and is not considered to be significantly different in chlorine resistance test performance to the unexposed sample.
7. Alternatively to the above methodology, a UV exposed sample could be tested and analyzed in accordance with ASTM F2023 (full data set). A result meeting the requirements of ASTM F876 would indicate that the chlorine resistance performance of the UV exposed pipe sample is acceptable.

An example of the calculations for a UV exposed commercial PEX pipe material is provided in Appendix C.

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Notes:

[a] Testing may be performed at any standard test condition as long as the following requirements are met:
- The same test condition is used for both sets of specimens (UV exposed and unexposed).
- All of the failures are Stage III brittle oxidative failures.

The 115 °C and 60 psig test condition is recommended for most samples as Stage III failures are generally observed at this condition and the test duration is relatively short.

[b] Testing of unexposed specimens is not required if an ASTM F2023 data set or equivalent is available. For the analysis, the EFT shall be calculated for the selected test condition and used in place of the average failure time for the unexposed specimens $\left(\bar{x}_{\text{Unexposed}}\right)$.

[c] Calculate the average failure time based on log(failure time) (in log(hours)). Convert from average log(failure time) to average failure time (in hours).

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Conclusions:

A total of eight ASTM F2023 and NSF P171 Protocol data sets were examined.

The proposed method is:

1. Chlorine resistance testing, in general accordance with the ASTM F2023 test methods, at 115 °C and 60 psig:
   - 5 UV exposed specimens
   - 5 unexposed specimens of the same sample lot or use the Expected Failure Time from a data set in accordance with ASTM F2023
2. Visually confirm that the failures are all Stage III brittle oxidative failures. If mixed-mode or Stage II failures are observed, testing at a different test condition shall be performed to ensure Stage III failures.
3. Calculate the average failure time for the UV exposed specimens $\left(\bar{x}_{\text{UV Exposed}}\right)$.
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5. Calculate the % Decrease in Failure Time of the UV exposed specimens relative to the unexposed specimens:

$$\%\ \textit{Decrease in Failure Time} = \left(1 - \frac{\bar{x}_{\text{UV Exposed}}}{\bar{x}_{\text{Unexposed}}}\right) \cdot 100\%$$

6. If the *% Decrease in Failure Time* is equal to or less than the *Maximum Allowable Decrease in Failure Time* of 21%, the UV exposed sample passes the requirement and is not considered to be significantly different in chlorine resistance test performance to the unexposed sample.
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7. Alternatively to the above methodology, a UV exposed sample could be tested and analyzed in accordance with ASTM F2023 (full data set). A result meeting the requirements of ASTM F876 would indicate that the chlorine resistance performance of the UV exposed pipe sample is acceptable.

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Appendix A

Range in *% Decrease in Failure Time* Values

The table below provides the overall range in values observed for each data set at each for the three temperatures. The range is generally consistent over the three temperatures.

Data Set	% Decrease in Failure Times					
	115 °C		105 °C		95 °C	
	Min	Max	Min	Max	Min	Max
A	12	15	11	16	12	18
B	15	17	15	17	16	18
C	19	21	19	21	20	22
D	20	21	19	21	20	22
E	19	24	19	26	20	28
F	22	25	21	23	22	25
G	21	25	21	27	22	30
H	29	32	28	32	30	33

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Appendix B

Additional Information Used in the Analysis

LPL Values

In the calculation of the *Maximum Allowable % Decrease In Failure Time*, LPL values were used instead of Lower Confidence Limits (LCL). LCL values are valid for the comparison between unexposed and UV exposed specimens where the data used to generate the Confidence Limits accounts for all sources of variation. However, the LCL values generated from a data set do not fully account for lot to lot variability as well as other variability that may arise from truly independent testing.

By using LPL values, which has wider limits, lot to lot and other sources of variability are considered when making comparisons against completed ASTM F2023 data sets.

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Appendix C

Example Calculation based on the Proposal

A ½" SDR-9 commercial PEX pipe material was exposed in Arizona and Florida for 2 months (generated in a Jana Research Project) followed by chlorine resistance testing at 115 °C and 60 psig. Details of the test results are provided in the table below. Note that only two specimens per sample were tested (based on available data) whereas the proposed methodology requires five specimens per sample.

Exposure Period	Sample ID	Failure Time (hours)	Average (log(Failure Time))	Average Failure Time (hours)
0	1	1473	3.17	1483
	2	1494	3.17	
2 months Arizona	3	715	2.85	761
	4	810	2.91	
2 months Florida	5	778	2.89	757
	6	736	2.87	

For the 2 month Arizona specimens, the % decrease is:

$$\left(1-\frac{761}{1483}\right)\cdot 100\% = 49\%$$

Similarly for the 2 month Florida specimens, the % decrease is:

$$\left(1-\frac{757}{1483}\right)\cdot 100\% = 49\%$$

For both sets of UV exposed specimens, the % decrease in failure time is 49% and above the maximum requirement value of 21%. Therefore, the UV exposed samples are considered to be significantly different in chlorine resistance test performance from the original unexposed sample.

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