

# AN EXAMINATION OF FIELD FAILURES OF PLASTIC PIPING SYSTEM COMPONENTS IN POTABLE WATER APPLICATIONS

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## Abstract

Disinfectants in potable water, such as chlorine and chlorine dioxide, can impact the performance of plastic piping system components. In this paper, field failures of plastic piping components exposed to potable water are examined. Analysis of the oxidative and mechanical initiation and propagation mechanisms leading to failure is performed. Field and laboratory samples are also compared to assess the test methodologies that are available to evaluate the impact of disinfectants on plastic piping systems.

## Background

Plastic piping materials have been used for a variety of applications since the 1940's. With the increase in the use of plastic piping systems and the variety of applications, several test methodologies have been developed and refined to forecast the long-term strength of these materials [1]. These test methodologies have defined three failure regimes that are typically observed for plastic piping materials:

- Stage I: Ductile-Mechanical Failure
- Stage II: Brittle-Mechanical Failure
- Stage III: Brittle-Oxidative Failure

Several test methodologies such as ASTM D2837, Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials [2], and ISO 9080, Plastics Piping and Ducting Systems – Determination of the Long-Term Hydrostatic Strength of Thermoplastics Materials in Pipe Form by Extrapolation [3], have been developed to characterize the mechanical performance (Stage I and Stage II) of plastic piping materials.

In the Stage III failure regime, the performance of a material is not only dependent on the mechanical strength but also on the resistance of a material to oxidative degradation. Exposure to different environments can accelerate the oxidative degradation process and result in shorter lifetimes. In potable water applications, disinfectants, such as chlorine and chlorine dioxide, are known to be oxidants that can accelerate this process. To ensure the performance of plastic piping materials in potable water applications, a test methodology has been developed for crosslinked polyethylene to characterize the Stage III brittle-oxidative performance in potable water (ASTM F2023, Test Method for Evaluating the Oxidative

Resistance of Crosslinked Polyethylene (PEX) Tubing and Systems to Hot Chlorinated Water [4]).

Other polyolefins, such as polyethylene, are also used for potable water applications. Due to the relatively low operating temperatures used with some polyolefins, oxidative degradation was generally not considered to be a significant factor impacting the performance in potable water applications. This consensus has been challenged as more information has been developed on the impact of disinfectants on the oxidative degradation process. The test method, ASTM F2263, Standard Test Method for Evaluating the Oxidative Resistance of Polyethylene (PE) Pipe to Chlorinated Water [5], has been developed, based on the ASTM F2023 test method, to evaluate the impact of disinfectants on polyethylene piping materials.

Field failures have validated the test methodologies used to characterize the performance of plastic piping materials in the Stage I and Stage II failure regimes. With cross-linked polyethylene, through years of testing and comparisons with field failures, the Stage III regime has also been validated [6, 7]. As the ASTM F2263 is still fairly new, validation is still in progress to compare field and laboratory failures and to validate the test methodology.

It was hypothesized that the failures of other polyolefin materials would be similar to that observed with PEX. However, accelerated laboratory testing based on the ASTM F2263 test method has shown that the failure modes observed with other polyolefins can be different from PEX and may not fall into the standard three stage failure regime. Based on the accelerated testing, the failures modes within the Stage II and Stage III failure regimes have been expanded further into four modes of failure [6]. These failure modes have been defined as:

- Mode 1: Mechanical Initiation-Mechanical Propagation (true Stage II)
- Mode 2: Mechanical Initiation-Oxidative Propagation
- Mode 3: Oxidative Initiation-Mechanical Propagation
- Mode 4: Oxidative Initiation-Oxidative Propagation (true Stage III)

The Mode 1 and 4 failure types are the standard Stage II and Stage III failure types, respectively. With the Mode 2 and 3 failure types, crack initiation and crack propagation differ from the standard failure types. Mode 2 failures initiate in a similar manner to a Stage II failure. However, crack propagation is dependent on the oxidative resistance

of the material. With a Mode 3 failure, the reverse of a Mode 2 failure is observed. Crack initiation is dependent on the oxidative resistance of the material. Once a crack initiates, crack propagation is dependent on the mechanical slow crack growth resistance of the material. Further details of the different failure modes are discussed in *Modeling Mechanisms of Brittle Oxidative Degradation to Ensure Plastic Pipe Material Performance* [6].

In this paper, polyolefin field samples with brittle failures will be examined and evaluated for the potential failure mode based on the four mode model. These failures will be compared to laboratory failures to assess the current test methodology and its method of evaluating the impact of potable water on polyolefin piping systems.

## Experimental

Several polyolefin field samples observed to have a brittle type of failure were examined. The failures were exhumed from service lines providing residential and commercial potable water. Optical Microscopy of the inner surface and fracture face was performed. Oxidation Induction Time (OIT) was performed in general accordance with ISO 11357-6-2002 (E) (8) at 200 °C from the inner and mid walls of the pipe specimens. Micro-attenuated total reflection Fourier Transform Infrared Spectroscopy (micro-ATR) was also performed on the inner surface and the fracture face.

## Results

### *Visual Examination and Optical Microscopy*

Visual examination of the failed samples showed varying levels of deposits on the inner surface. Micro-cracking of the inner surface, an indication of embrittlement, was also observed to vary. A reverse bend test was performed to examine the levels of degradation. Figures 1 and 2 provide photographs of the inner surface of three samples prior to and after a reverse bend test was performed. Prior to the reverse bend test, observations ranged from no micro-cracking to minor micro-cracks that were visible to the naked eye. Upon reverse bend of a specimen, observations ranged from no micro-cracking to crazing and minor cracking of the inner surface to fracture of the specimen (Figures 2a, 2b and 2c, respectively). It would appear that the level of degradation varies among the samples examined.

The fracture face of the failed samples has features that are generally consistent with slow crack growth and brittle-mechanical Stage II failure. Slow crack growth rings are observed in several of the specimens. Selected photographs are provided in Figure 3.

### **OIT**

Table 1 provides a summary of the OIT results from the inner surface and the mid wall of the failed samples. The OIT values at the inner surface of all of the samples are observed to be low, with essentially no stabilizer remaining in the inner surfaces. At the mid wall, the OIT values are generally higher than at the inner surface.

### **FTIR**

FTIR was performed at the inner surface, mid wall (away from the fracture face), through the fracture face and at the crack front. A photograph showing an example of the different locations is provided in Figure 4. Figure 5 shows a sample FTIR spectrum. The carbonyl ratios, a measure of the level of degradation evaluated between 1812 and 1660  $\text{cm}^{-1}$ , were calculated and are provided in Table 2. The highest level of degradation is observed on the inner surface and decreases through the fracture face. Away from the fracture face and at the crack front, minimal or no degradation is observed.

## Discussion

In general, the failed samples are observed to have the following features:

- Degradation of the inner surface as evidenced by micro-cracking, low OIT values and the carbonyl ratios
- Varying levels of degradation of the fracture face ranging from none to minor levels which decrease from the inner to the outer surface
- No degradation at the crack front
- Fracture face characteristics that are generally consistent with slow crack growth characteristics

The lack of a visible degradation layer with many micro-cracks on the inner surface and the low levels of degradation through the fracture face suggest that the failures are not true Stage III brittle oxidative failures. Conversely, the presence of the degradation layer observed by FTIR and the reverse bend test suggest that the failures are not completely brittle mechanical Stage II in nature. Based on these observations, it would appear that the failures are generally consistent with the Mode 3 Oxidative Initiation-Mechanical Propagation type of failure.

Although the majority of the samples appear to be Mode 3 failures, it is observed that the level of degradation and cracking can vary within this type of failure. These observed differences are likely due to differences between materials as degradation and micro-cracking are dependent on the stabilizer package and the slow crack growth resistance of the sample. Because Mode 3 failures are dependent on both the oxidative stability and the slow

crack growth resistance of the material, the Mode 3 failure can be considered to be more of a continuum between the Stage II and Stage III failure regimes.

Several samples, similar to Sample C, do not appear to fall into the Mode 3 category. The reverse bend test of these samples does not indicate significant degradation or micro-cracking of the inner surface. As well, through the fracture face, minimal or no degradation is observed. Examination of the fracture face suggests that these samples failed in a Stage II manner due to external loads, such as rock impingement, that were present during service. Further examination of these types of failures will be presented in a future paper.

**Comparison to Laboratory Failures**

Figures 6 and 7 provide photographs of a laboratory polyolefin failed sample tested in accordance with ASTM F2263. In Figure 6, it is observed that the inner surface appears to have no micro-cracks. However, upon the reverse bend test, micro-cracks are visible on the inner surface. Through the fracture face, the sample has the typical Stage II slow crack growth characteristics. Based on these observations, it would appear that the laboratory failures are also Mode 3 failures.

**Conclusions**

Examination of the field polyolefin failures has shown that exposure to potable water can result in Mode 3 failures. These failures are consistent with accelerated laboratory failures indicating that the ASTM F2263 test methodology is a valid method of examining the impact of disinfectants in potable water on the performance lifetime of polyolefin piping materials.

**Acknowledgments**

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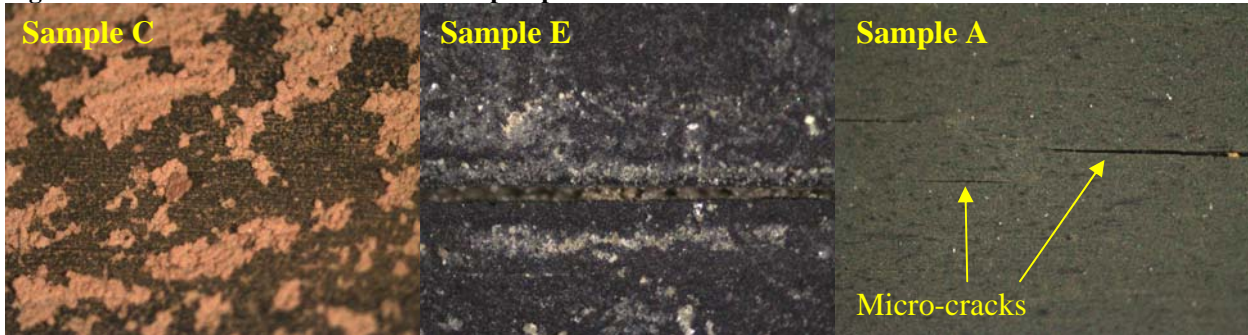
**Table 1: Summary of OIT Results**

Sample	OIT (minutes)	
	Inner Surface	Mid Wall
A	0.19	6.0
B	0.40	5.2
C	0.18	0.17
D	0.24	0.90
E	0.22	39
F	0.26	9.2
G	0.48	16

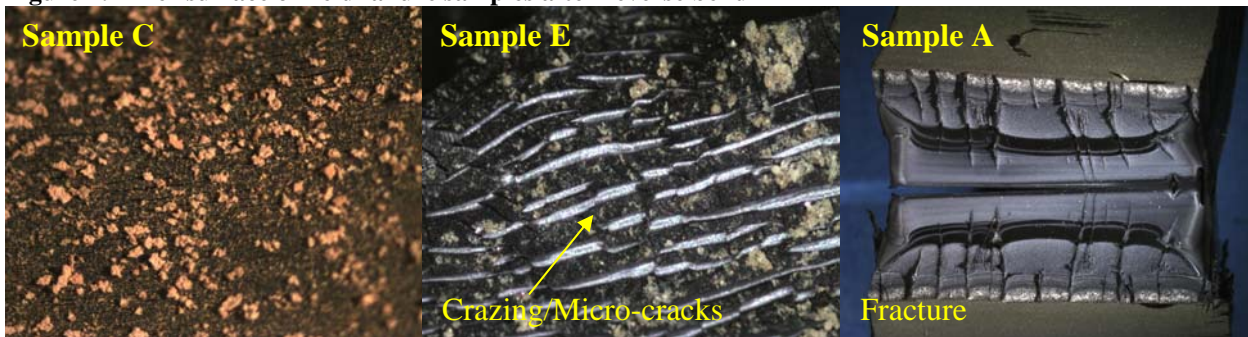
**Table 2: Summary of FTIR Results**

Sample	Carbonyl Ratio				Crack Front
	Inner Surface	Mid Wall	Fracture Face		
			Mid Wall	Mid-Outer Wall	
A	0.54	0	0.04	0.09	0
C	0.06	0	0	0.04	-
E	0.34	0.02	0.15	0.01	0

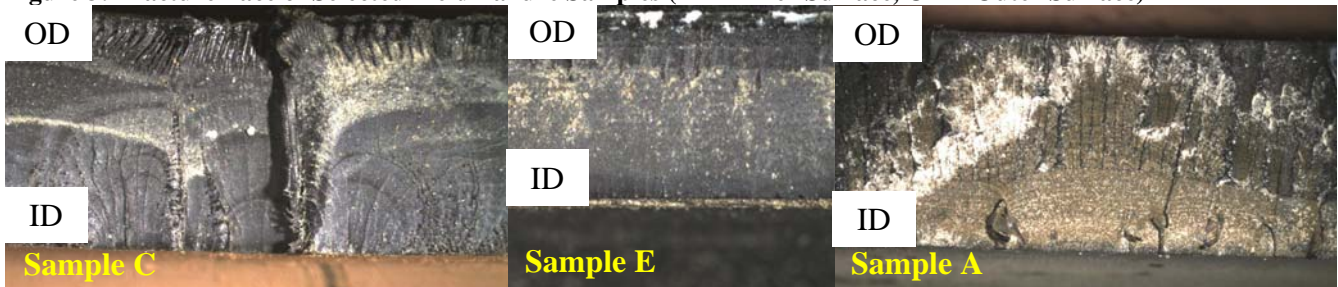
**Figure 1: Inner surface of field failure samples prior to reverse bend**



**Figure 2: Inner surface of field failure samples after reverse bend**



**Figure 3: Fracture Face of Selected Field Failure Samples (ID = Inner Surface, OD = Outer Surface)**



**Figure 4: Example of FTIR Locations**

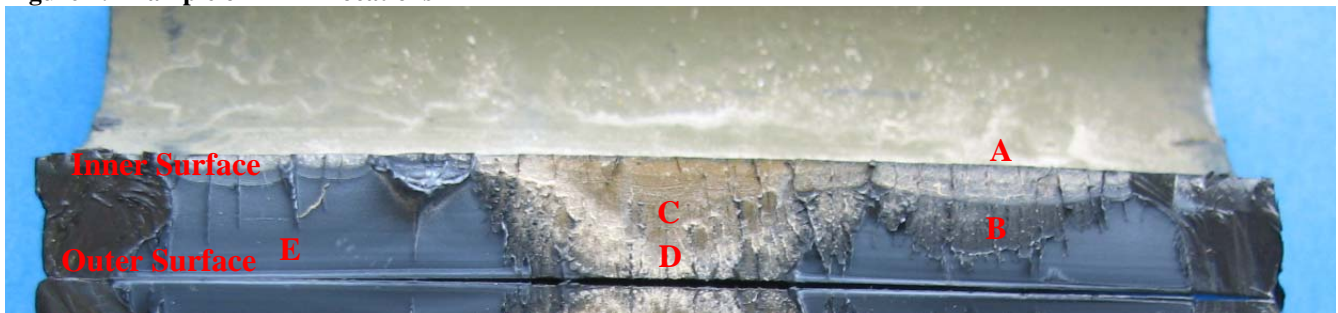


Figure 5: FTIR of Sample A

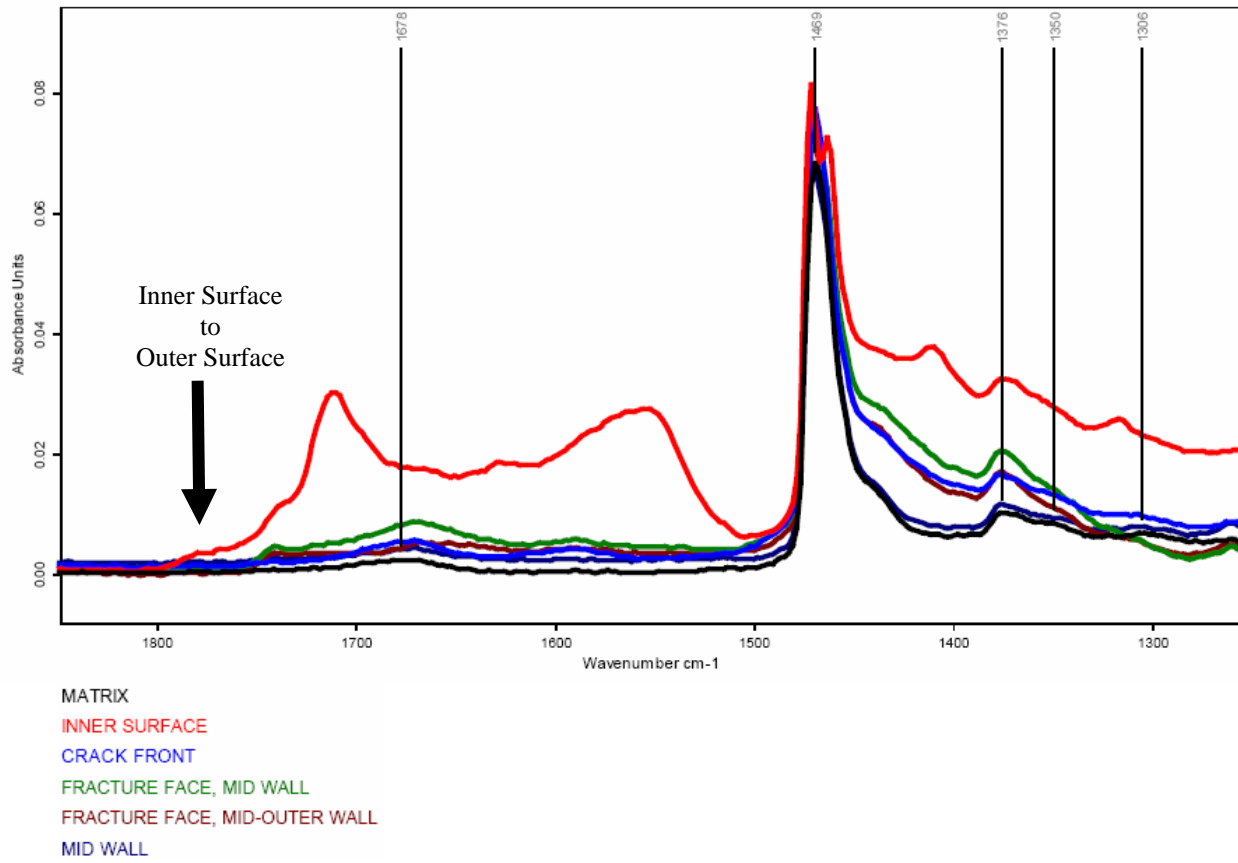


Figure 6: Inner surface of laboratory failure samples prior to and after reverse bend

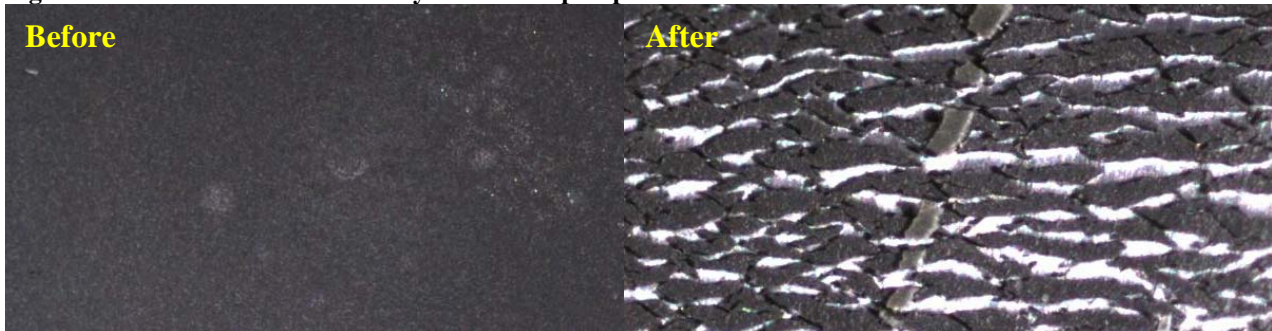


Figure 7: Fracture Face of Laboratory Failure Samples

