

## Corrosion Resistance of Victaulic® Styles 904, 905, 907, W907, and 908 Couplings In Buried Service Applications

### Executive Summary:

*Victaulic* Styles 904, 905, 907, W907, and 908 mechanical couplings for joining High Density Polyethylene (HDPE) pipe are suitable for direct burial. The ductile iron coupling housings and the fluoropolymer-coated zinc-electroplated carbon steel hardware have a long track record of successful service in direct buried piping applications.

This document provides a guideline for the reader by considering the corrosion resistance of metallic components in *Victaulic* Styles 904, 905, 907, W907, and 908 couplings, incorporating accepted measures to quantifying soil corrosiveness and internationally recognized corrosion control standards. Various enhancements such as “industry standard” coatings (liquid and fusion bond epoxy, hot dip galvanizing, etc.), protective wraps, cathodic protection (zinc or magnesium anodes), and/or alternate materials of construction (stainless steel hardware) are available at the project material specifier’s option for aggressive environments.

Soil corrosiveness varies geographically and depends upon many factors, including but not limited to: pH, presence of ground water, chlorides, soil type and gradation, chemical contaminants, and stray electrical currents. This report introduces the 10-point method from ANSI/AWWA C105 as one method to quantify potential soil corrosivity effects on *Victaulic* Styles 904, 905, 907, W907, and 908 couplings. The report also predicts useful life per ISO 9224, correlating data from ISO 12944 C5-M marine environment salt spray testing of fluoropolymer-coated bolts with results from the Ductile Iron Pipe Research Association’s 75-year buried iron pipe studies. This analysis focused on the coupling hardware, as evaluation of the other components showed them to be less susceptible to deleterious effects of corrosive soil, based on either their material of construction or their lower level of applied stress.

Soil corrosiveness is a global issue that requires local solutions. Local codes, local jurisdictional authorities, customary practices, jobsite specifications, etc., all may take precedence over the information presented in this guideline. However, using generally accepted methods and recognized industry standards, “off the shelf” *Victaulic* Styles 904, 905, 907, W907, and 908 couplings with fluoropolymer-coated hardware will have appreciably more than a 50-year life expectancy in a modestly corrosive soil, per AWWA C105 Appendix A. Additional means of corrosion control are available to further protect the products in more aggressive soil conditions and to extend the life of all components.

### Introduction:

Direct buried piping systems are one of the original applications for *Victaulic* couplings. *Victaulic* pipe joining technology has been incorporated successfully in buried services for over 85 years, with installations dating back to the 1930s. Standard *Victaulic* grooved couplings, manufactured from ductile iron meeting the requirements of ASTM A536 Grade 65-45-12 with zinc-electroplated carbon steel hardware, maintain joint integrity for most underground piping systems. Piping system designers, based upon local conditions, codes, and service environments, may choose to incorporate external coatings such as fusion bonded epoxy, liquid epoxy, and polyurethane, as well as external coverings such as heat shrink, tapes or wraps, mastics, and wax, to ensure that buried system components are properly protected against corrosion. Where desired by the piping system designer, *Victaulic* offers optional factory-applied coatings and hardware alternatives to add corrosion protection in more corrosive environments in addition to the standard hardware discussed in this paper.

*Victaulic*’s products such as Styles 904, 905, 907, W907, and 908 couplings are designed for High Density Polyethylene (HDPE) piping systems, which are commonly used in buried service. Corrosion concerns may arise when steel or other ferrous components are introduced in direct buried HDPE piping systems that are exposed to corrosive environments. Corrosion resistance of the coupling hardware (bolts, nuts, etc.) are of specific interest and will be discussed in this paper. Other components of the coupling (housings, retainers, and gaskets) are predicted to represent less of a corrosion concern to designers than the coupling hardware.

To align with our efforts to bring new technology improvements to the market, Victaulic offers mechanical couplings with fluoropolymer-coated hardware for all HDPE applications, including buried services. This technical report discusses the testing and qualification of coupling hardware with the fluoropolymer coating applied over the standard zinc electroplating when exposed to harsh service conditions. ***Victaulic's fluoropolymer-coated hardware is projected to have a 50+ year service life in less than "10-point soil" per Appendix A of ANSI/AWWA C105/A21.2. A number of industry-accepted corrosion control options are available if additional corrosion control is deemed necessary.***

## Salt Spray Testing (Atmospheric Exposure):

External corrosion of steel in soil can be affected by a number of variables, such as moisture, pH, resistivity, chloride/sulfide ion content, and presence of corrosion-activating bacteria. Corrosivity is often characterized by a bare metal corrosion rate in a specific environment. In order to predict the performance of a coating, it is necessary to understand the corrosivity of the environment.

Considering that the corrosivity of the environments for specific installations may not be known, Victaulic utilizes corrosivity categories as defined by ISO 12944-2<sup>2</sup> to test hardware coating effectiveness. ISO 12944-2 atmospheric corrosivity categories are shown in Figure 2. *Victaulic* fluoropolymer-coated hardware was utilized on Style 905 couplings that joined HDPE pipe to simulate the mechanical forces resulting from a field installation. The entire assembly (as shown in Figure 3a) was then subjected to 1000 hours of salt spray conditions, simulating the first year of service life in the C5-M environment following the test method specified in ISO 12944-6.<sup>3</sup> Test results (as shown in Figure 4) reveal that *Victaulic* fluoropolymer-coated hardware show less than 5% red rust following the 1000-hr test. The highest area of interest is the exposed threaded portion of the bolt beneath the nut, which represents the maximum stress concentration. Examination of the threaded portion of the bolt indicates good adhesion of the fluoropolymer coating and only minor onset of corrosion. The white corrosion product on the external surfaces of the nut outside diameter is an indication that the zinc electroplating is corroding. However, corrosion on the nut is less significant in comparison to the exposed threaded portion of the bolt.

The same salt spray testing has also been performed on a Style 905 assembly with zinc-electroplated carbon steel hardware without the fluoropolymer coating for comparison. The resulting red rust is nearly 100% on exposed areas after the 1000-hr test (as shown in Figure 5). The calculated corrosion loss per ISO 9223<sup>4</sup> for *Victaulic* fluoropolymer-coated zinc-electroplated hardware in the most aggressive corrosivity category of C5-M is 74 µm (2.9 mil) for first-year exposure, compared to 750 µm (29.5 mil) first-year thickness loss for uncoated carbon steel hardware.

Corrosivity category	Mass loss per unit surface/thickness loss (after first year of exposure)				Examples of typical environments in a temperate climate (informative only)	
	Low-carbon steel		Zinc		Exterior	Interior
	Mass loss g/m <sup>2</sup>	Thickness loss µm	Mass loss g/m <sup>2</sup>	Thickness loss µm		
C1 very low	< 10	< 1,3	< 0,7	< 0,1	–	Heated buildings with clean atmospheres, e.g. offices, shops, schools, hotels
C2 low	> 10 to 200	> 1,3 to 25	> 0,7 to 5	> 0,1 to 0,7	Atmospheres with low level of pollution. Mostly rural areas.	Unheated buildings where condensation may occur, e.g. depots, sports halls.
C3 medium	> 200 to 400	> 25 to 50	> 5 to 15	> 0,7 to 2,1	Urban and industrial atmospheres, moderate sulfur dioxide pollution. Coastal areas with low salinity.	Production rooms with high humidity and some air pollution, e.g. food-processing plants, laundries, breweries, dairies.
C4 high	> 400 to 650	> 50 to 80	> 15 to 30	> 2,1 to 4,2	Industrial areas and coastal areas with moderate salinity.	Chemical plants, swimming pools, coastal ship- and boatyards
C5-I very high (industrial)	> 650 to 1 500	> 80 to 200	> 30 to 60	> 4,2 to 8,4	Industrial areas with high humidity and aggressive atmosphere.	Buildings or areas with almost permanent condensation and with high pollution.
C5-M very high (marine)	> 650 to 1 500	> 80 to 200	> 30 to 60	> 4,2 to 8,4	Coastal and offshore areas with high salinity.	Buildings or areas with almost permanent condensation and with high pollution.

**NOTES** 1 The loss values used for the corrosivity categories are identical to those given in ISO 9223.

2 In coastal areas in hot, humid zones, the mass or thickness losses can exceed the limits of category C5-M. Special precautions must therefore be taken when selecting protective paint systems for structures in such areas.

Figure 2: Corrosivity Categories from ISO 12944-2



Figure 3a: Style 905 assembly before the 1000-hr C5-M salt spray testing



Figure 3b: Style 905 assembly after the 1000-hr C5-M salt spray testing



Figure 4: Victaulic fluoropolymer-coated hardware after 1000hr C5-M salt spray testing



Figure 5: Zinc-electroplated carbon steel hardware after 1000hr C5-M salt spray testing

In order to predict the long-term performance of Victaulic's couplings in a severe corrosive environment, evaluation of *Victaulic* fluoropolymer-coated hardware exposed in the C5-M environment was conducted. The methodology to estimate the total thickness loss of fluoropolymer-coated zinc-electroplated carbon steel hardware follows an established corrosion prediction model from ISO 9224.<sup>5</sup> The model is based on three factors: (1) first-year corrosion rate of fluoropolymer coating, calculated from ISO 12944-6 testing, (2) logarithmic corrosion rate for carbon steel base metal, for exposure up to 20 years in duration and (3) a linear corrosion rate for carbon steel base metal, for exposure of more than 20 years. This conservative approach does not take into account the added corrosion protection from the zinc electroplating. The first-year corrosion rate is based on the accelerated salt spray testing.

Based on the information above, equations (1) and (2) from ISO 9224 were used to determine the logarithmic corrosion rate and linear corrosion rate, respectively.

$$(1) \quad D(t < 20) = r_{corr} * t^b$$

$$(2) \quad D(t > 20) = r_{corr} [20^b + b(20^{b-1})(t-20)]$$

where

$D$  is the total attack in penetration depth in micrometers;

$t$  is the exposure time in years;

$r_{corr}$  is the first-year corrosion rate in micrometers per year;

$b$  is the metal-environment-specific time exponent, and is calculated from the elemental composition of the base metal, per Annex C of ISO 9224

$r_{corr}$  for *Victaulic* fluoropolymer-coated hardware in the C5-M environment is estimated to be 74  $\mu\text{m}/\text{year}$  from the ISO 12944-6 testing.

The prediction of maximum corrosion attack in terms of total thickness loss for *Victaulic* fluoropolymer-coated bolts after extended exposure in a C5-M environment is represented by the blue line in Figure 6.

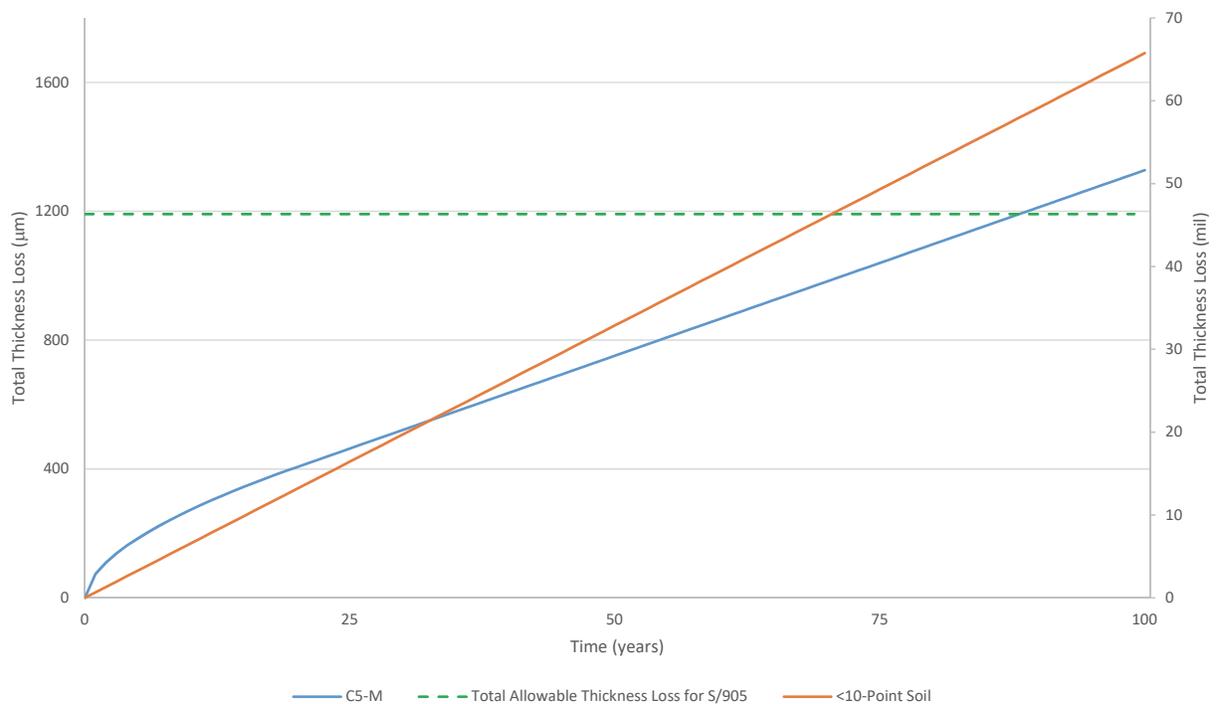


Figure 6: Useful Life Prediction for *Victaulic* fluoropolymer-coated bolt in C5-M and <10-point soil environments

## Buried Service Evaluation:

To correlate the corrosivity categories in ISO 12944-2 with buried service conditions, a number of published corrosion rates for buried cast iron and ductile iron pipe were reviewed. These publications include Ductile Iron Pipe Research Association (DIPRA), Bonds et. al,<sup>6</sup> Wakelin and Gummow,<sup>7</sup> Szeliga,<sup>8</sup> National Bureau of Standards (NBS) (now National Institute of Standards and Technology [NIST]), Romanoff,<sup>9</sup> and National Academies National Research Council (NRC)<sup>10</sup>. Despite the extent of this prior work, there are no universally agreed-upon factors or methodologies for determining soil corrosiveness. The NACE International (NACE) technical task group on “Corrosion Control of Ductile and Cast Iron Pipe”<sup>11</sup> reported the following list of most frequently mentioned factors for buried iron pipe corrosion:

1. Resistivity/conductivity;
2. Alkalinity and pH;
3. Soil type and gradation;
4. Microbiological activity;
5. Moisture;
6. Nonhomogeneous environments;
7. Changing groundwater conditions;
8. Dissolved salts (chlorides, sulfates, etc.);
9. Cinders and carbon deposits; and
10. Chemical contaminants

Romanoff<sup>9</sup> compared earlier NBS cast iron studies to later studies of ductile iron pipe, and reported “iron and ductile iron corrode at nearly the same rate in the same soil environment.” Bonds’ study also stated that “overall results indicated that the corrosion pitting rates of ductile iron versus gray-iron pipe were soil specific to an extent but were essentially the same statistically (t-tests, 95% confidence).”<sup>12</sup> Based on the NBS and Bonds study, the NRC<sup>10</sup> committee also considered cast-iron and ductile-iron corrosion rates to be similar. In this paper, corrosion rates of cast iron pipe and ductile iron pipe are assumed to be the same under the same buried conditions. For the purpose of discussion in this paper, the term “iron pipe” includes both cast iron pipe and ductile iron pipe.

Unlike the above-ground corrosion prediction model generated for bare metals and alloys from ISO 9224, there is no universally accepted corrosion kinetics established for buried iron pipe. This is due to the wide range of conditions encountered, which can change with time and are not definable. However, there are a number of different soil evaluation systems to provide guidance for rating soil corrosiveness in order to determine whether corrosion control is needed. One widely used method generally accepted by the iron pipe industry is the 10-point system, as included in Appendix A of the ANSI/AWWA Standard C105/A21.5 (1999).<sup>13</sup> Table 1 shows the 10-point soil test parameters, which include soil resistivity, pH, redox potential, sulfides, and moisture. For a given soil sample, each parameter is evaluated and assigned points according to its contribution to corrosiveness. The points for all five soil characteristics are totaled. If the sum is 10 or more, the soil is considered corrosive to iron pipe, and corrosion is likely to occur during the pipe’s service life unless protective measures are taken. This 10-point system also states that soil environments such as the following are considered potentially corrosive to iron pipe, and therefore evaluation is not required to determine the need for corrosion protection:

1. Coal
2. Cinders
3. Mucks
4. Peat
5. Mine wastes
6. Landfill areas

Existing installations and the potential for stray direct-current corrosion should also be a part of the evaluation. Additionally, it is important to note that neither the 10-point method from AWWA C105 nor other similar methods are effective in quantifying the amount of corrosion on iron pipe. For example, a 20-point soil is not necessarily more aggressive than a 12-point soil, and hence the 20-point soil might not generate more corrosion on iron pipe than would the 12-point soil. Szeliga et. al.,<sup>8</sup> in their analyses of data from operating mains, confirmed that the 10-point system did not correlate with the actual rate of corrosion on ductile iron mains. Nevertheless, the 10-point system provides good guidance in identifying soil environments that are potentially corrosive to iron pipe.

Soil Characteristics	Points*
<b>Resistivity—<math>\Omega\text{cm}^\dagger</math></b>	
<1,500	10
$\geq 1,500 - 1,800$	8
$>1,800 - 2,100$	5
$>2,100 - 2,500$	2
$>2,500 - 3,000$	1
$>3,000$	0
<b>pH</b>	
0 - 2	5
2 - 4	3
4 - 6.5	0
6.5 - 7.5	0‡
7.5 - 8.5	0
$>8.5$	3
<b>Redox potential—mV</b>	
$>+100$	0
$+50 - +100$	3.5
$0 - +50$	4
Negative	5
<b>Sulfides</b>	
Positive	3.5
Trace	2
Negative	0
<b>Moisture</b>	
Poor drainage, continuously wet	2
Fair drainage, generally moist	1
Good drainage, generally dry	0

**NOTES:**

\* 10 points: corrosive to iron pipe; protection is indicated.

† Based on water-saturated soil box. This method is designed to obtain the lowest and most accurate resistivity reading.

‡ If sulfides are present and low (<100 mV) or negative redox-potential results are obtained, three points should be given for this range.

Table 1: 10-Point soil test evaluation per AWWA C105/A21.5-10

Among all the buried iron pipe studies mentioned above, DIPRA has the most extensive field test data in different soils in the United States. Its database consists of more than 60,000 entries, and includes research on more than 2,000 specimens and inspections extending over a 75-year period. Bonds<sup>16</sup> statistical analysis involves a large subset of DIPRA's data, representing more than 300 soil environments. The 10-point soil system, per AWWA C105, was used to evaluate corrosion potential with respect to iron pipe in Bonds' analysis. The reported mean maximum pitting rate corresponds to approximately 16.7  $\mu\text{m}$  (0.66 mil) for as-manufactured (asphaltic shop coated) iron pipe in soil conditions under 10 points (non-aggressive). Although corrosion kinetics are known to be nonlinear, with rates of corrosion decreasing over time,<sup>14</sup> most underground corrosion rates are assumed to be constant over time for simplicity and conservatism. Utilizing the 16.7  $\mu\text{m}/\text{year}$  linear corrosion rate from Bonds' analysis, prediction of corrosion attack in terms of total thickness loss for Victaulic fluoropolymer-coated steel bolts after extended exposure to a <10-point soil environment is represented by the orange line in Figure 6.

The area of greatest interest for corrosion analysis of Victaulic's fluoropolymer-coated mechanical coupling hardware is considered to be the exposed threaded portion of the bolt beneath the nut. During a corrosion attack at this location, the corrosion would cause the bolt shank to reduce in diameter. The service life of the bolt would be exceeded when the combined stresses of installation torque and operating pressure

exceeds the minimum yield strength of the bolt. In this analysis, using the minimum yield strength of the *Victaulic* fluoropolymer-coated hardware on the thickest compatible HDPE pipe at maximum rated operating pressure, the designs of *Victaulic* Styles 904, 905, 907, W907, and 908 would allow up to 1191.3  $\mu\text{m}$  (46.9 mil) bolt shank reduction in terms of thickness loss, and is represented by the green line in Figure 6. Comparing the allowable bolt shank reduction to the thickness loss generated by the test environments, *Victaulic's* fluoropolymer-coated hardware will have 50+ years of service life in the C5-M and <10-point soil environments.

## Corrosion Control:

Due to the complexity of underground corrosion, it is difficult to determine the level of corrosion control needed (if any) for specific soil conditions for long-term performance. Corrosion protection for *Victaulic's* products can be considered for any one or combination of reasons below:

1. Extending service life for <10-point non-aggressive soil for greater than 50 years of service
2. Aggressive soil conditions >10 points
3. Absence of soil survey data
4. "Known corrosive environments" such as coal, cinders, muck, peat, and landfills, per Appendix A of ANSI/AWWA C105/A21.2
5. Corrosion potential of existing installations in same soil conditions
6. As specified by the end-user/application

If corrosion control is deemed necessary, there are a number of industry-accepted corrosion control options available for Styles 905, 907, and 908 couplings and/or hardware. They include, but are not limited to, the following:

- 316 Stainless steel fasteners meeting ASTM F593 Group 2 (for soils not aggressive to 316SS material)
- AWWA C105<sup>13</sup> polyethylene sleeve
- AWWA C210<sup>15</sup> liquid epoxy coatings and linings
- AWWA C213<sup>16</sup> fusion-bonded epoxy coatings and linings
- AWWA C214<sup>17</sup> tape coatings
- AWWA C216<sup>18</sup> heat shrink
- AWWA C217<sup>19</sup> petrolatum and petroleum wax tape
- Sacrificial anodes for providing cathodic protection per AWWA M2720

## Conclusion:

*Victaulic* Styles 905, 907, and 908 mechanical couplings for joining High Density Polyethylene (HDPE) pipe are suitable for direct burial. Using industry recognized standards, "off the shelf" *Victaulic* Styles 904, 905, 907, W907, and 908 couplings with fluoropolymer-coated hardware will have appreciably more than a 50-year life expectancy in soils with <10 points, based on AWWA C105. In more aggressive soil conditions, additional means of corrosion control are available to extend product life.

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17. AWWA C214, Tape Coatings for Steel Water Pipelines.
18. AWWA C216, Heat-Shrinkable Cross-Linked Polyolefin Coatings for Steel Water Pipe and Fittings.
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