Pipe Fabrication Institute Engineering Standard ES-50

Internal Oxidation for Piping Welds

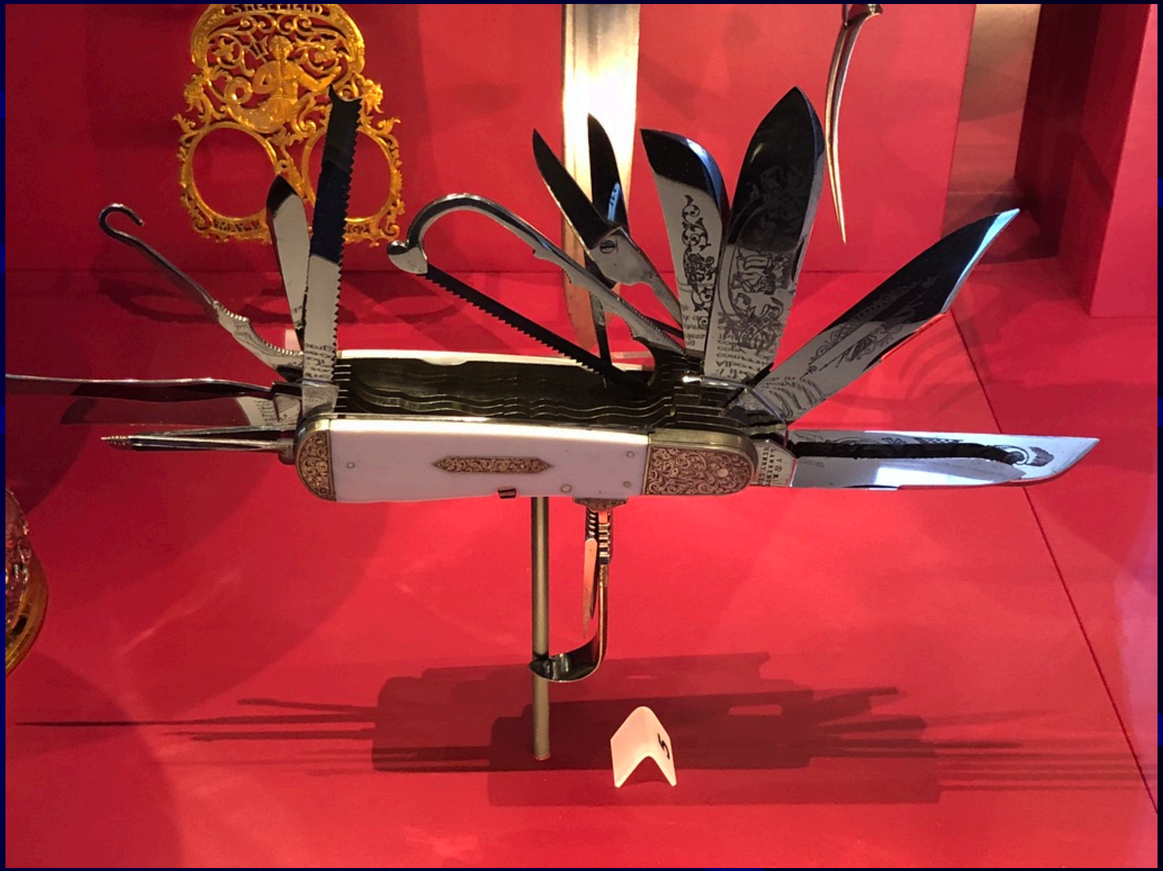
Walter J. Sperko, P.E.
Sperko Engineering Services, Inc.
Greensboro, NC
Sperko@asme.org

Origins of PFI ES-50

Stainless Steel was developed at Brown Firth Research Laboratories in Sheffield, England by Harry Brearley. The first heat of stainless steel was melted on 13 August 1913; it contained 12.8% chromium. Its primary use was in making rustproof cutlery.

Origins of PFI ES-50

Sheffield Stainless Multi-tool from the 1920s



Origins of PFI ES-50

- Austenitic Stainless Steel was developed by W. H. Hatfield at Firth-Vickers in 1924 and was marketed under the trade name "Staybrite 18/8"
- That's type 304. . .

Origins of PFI ES-50

What makes stainless steel "rustproof?"

- Chromium oxide film on the surface. It forms naturally with exposure to the atmosphere.
- The oxide layer "passivates" the underlying steel making it resistant to further oxidation and chemical attack in aggressive environments.
- In mild environments like potable water, surface contaminants can set up corrosion cells that lead to pitting attack.

Origins of PFI ES-50

The outlet was made using plasma to cut the hole in the type 316L header so that the branch pipe could be welded to the header.

Origins of PFI ES-50

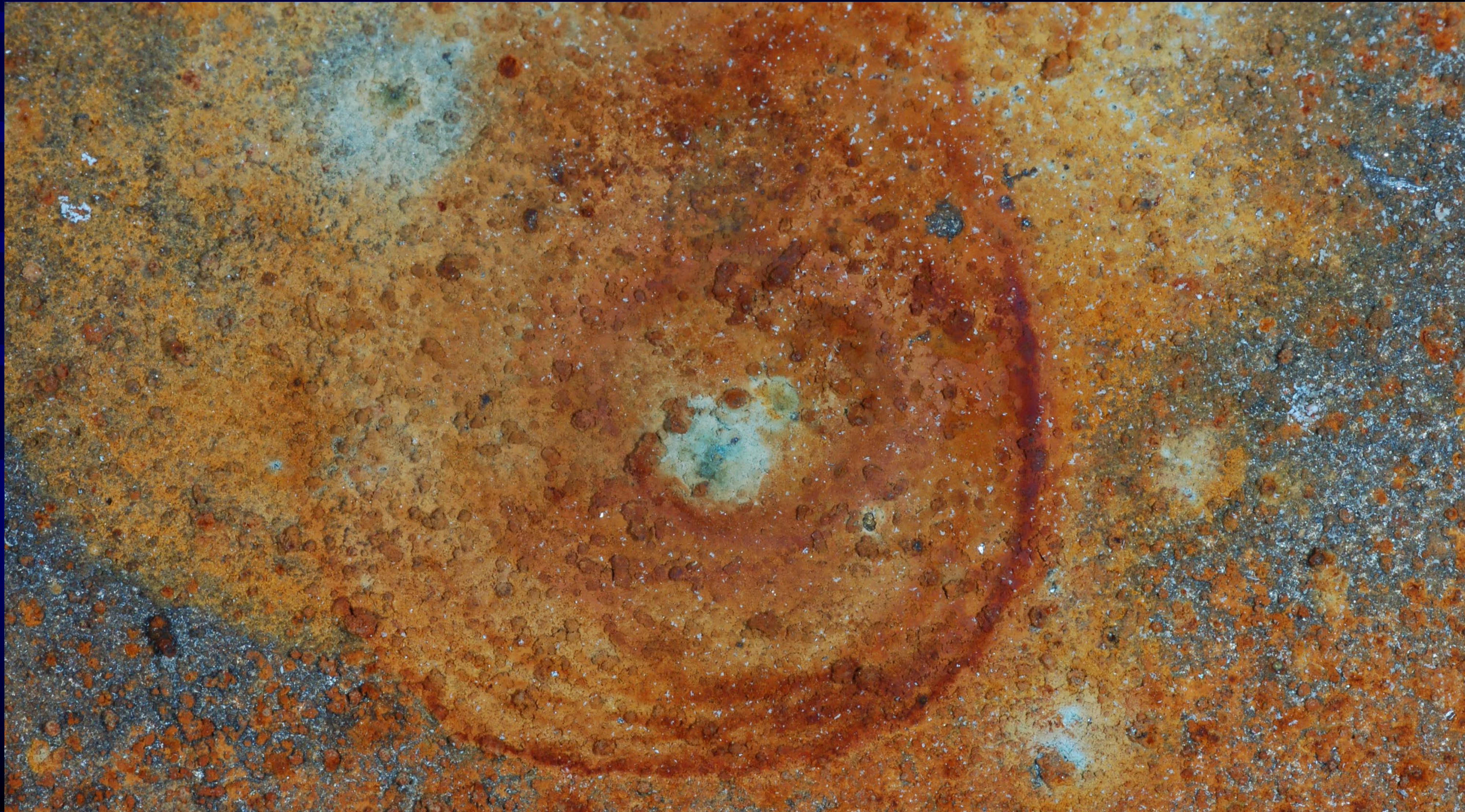
The cutting dross was not removed.

Service was potable water.

Origins of PFI ES-50

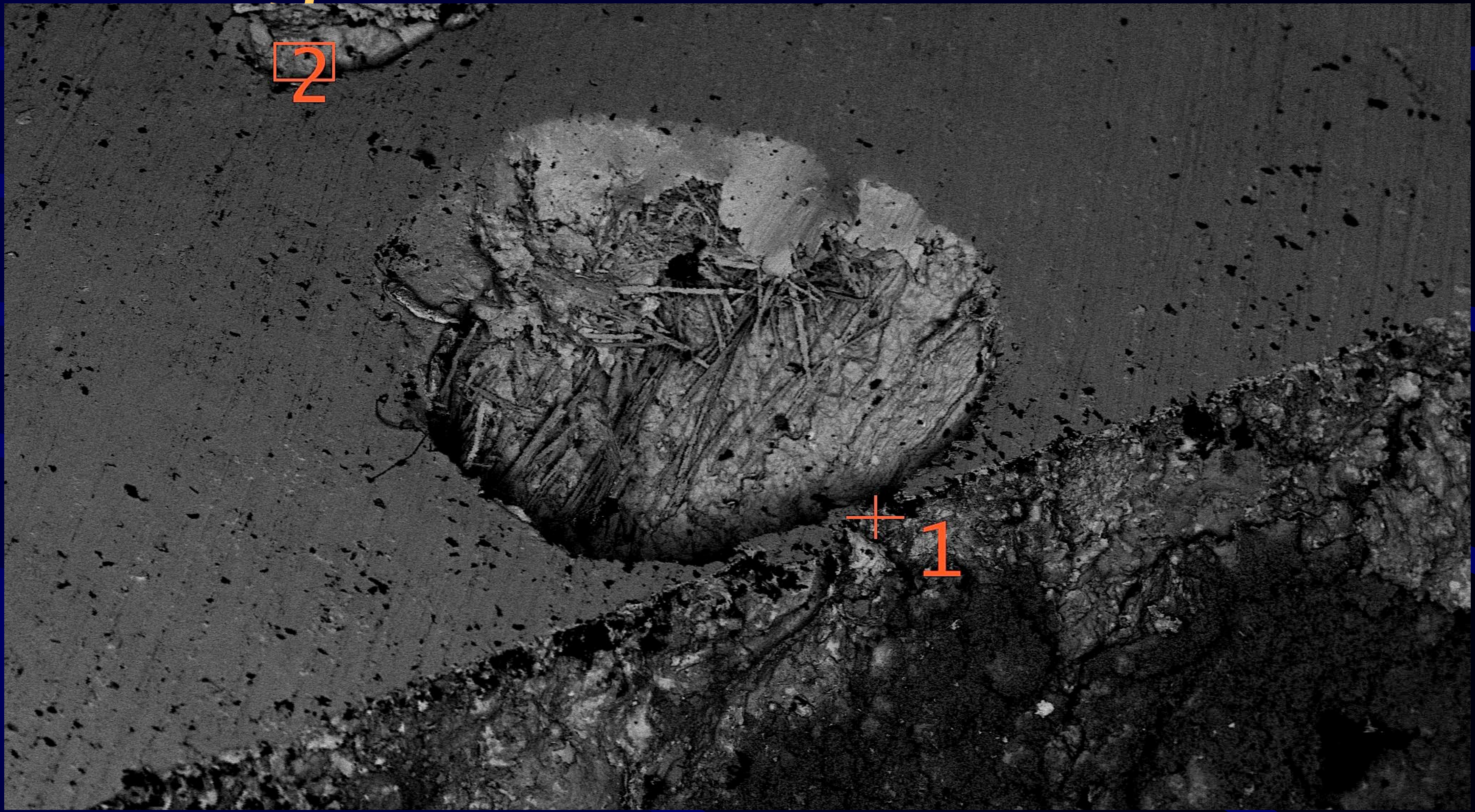
After 2 months in service, leaks were noticed.

Examination showed pitting around the cutting dross.



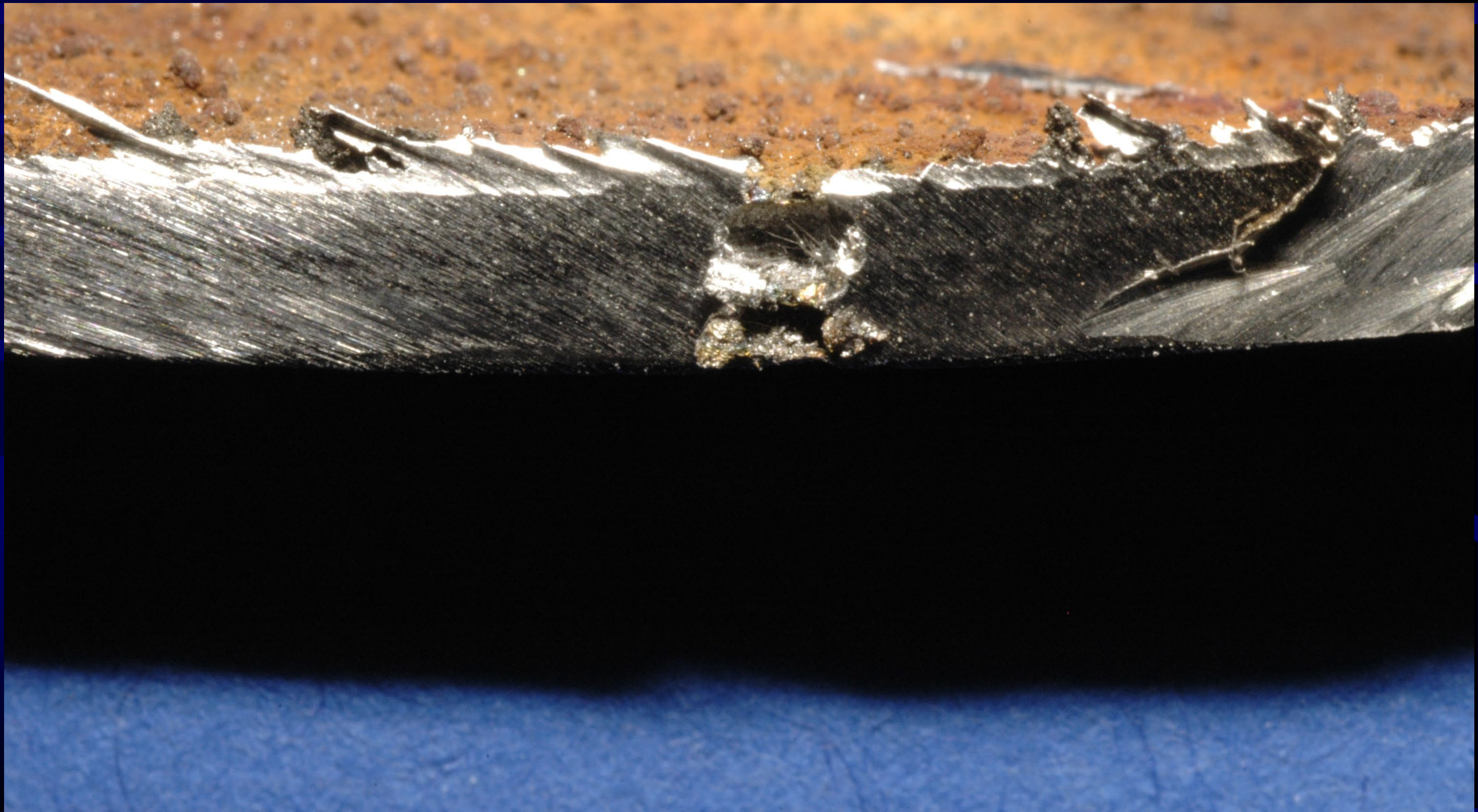
Origins of PFI ES-50

Plasma cutting slag deposited on the inside of a 316L potable water line caused pitting



Origins of PFI ES-50

Plasma cutting slag deposited on the inside of a 316L potable water line caused pitting that led to leaks at each branch location.



Origins of PFI ES-50

In mild environments like potable water, surface contaminants can set up corrosion cells in stainless steel that can lead to pitting attack and leaks.

- Internal surfaces need to be clean and free of contamination for optimum performance in environments where the fluid being handled is electrically conductive.
- Pitting attack is not a concern when the fluid being handled is nonconductive.

Root pass in carbon steel.

No gas backing.

Origins of PFI ES-50

Weld made using GTAW open root and no gas backing

Origins of PFI ES-50

- When welding **carbon steel** piping from the outside using GTAW with the root surface exposed to the air, the oxides that form on the weld pool surface are iron, silicon and manganese oxides. These oxides melt at around 2100 to 2400° F. Carbon steel melts at around 2750° F.
- The oxides that form on a carbon steel weld pool that is exposed to the atmosphere float on the surface as liquids.

Origins of PFI ES-50

- When welding **stainless steel** piping from the outside using GTAW with the root surface exposed to the air, the oxides that form on the weld pool surface are iron and chromium oxides. These oxides melt at around 2100 and 4400° F respectively. Stainless steel melts at around 2650° F.
- The oxides that form on a stainless steel weld pool that is exposed to the atmosphere form a semi-solid slush on the weld pool surface.

Origins of PFI ES-50

Weld made using GTAW open root without gas backing

Weld made using argon + 5% hydrogen gas backing, 1 ppm oxygen

Origins of PFI ES-50

This surface can be ground smooth and clean and it will perform just as well as the previous slide condition.

Origins of PFI ES-50

You can't always get to the root side to clean it up, so you have to protect the root side weld metal from the air sufficiently that you can be inspect it for penetration and freedom from cracking or other flaws.

Some have used the shielding gas from the torch flowing through the root opening and (somewhat) protecting the root surface from the oxygen in the air.

Root pass made on 304L stainless using GMAW waveform-controlled welding, open root, no gas backing. This weld is inspectable.

Origins of PFI ES-50

The weld surface and adjoining base metal are heavily oxidized. This may or may not be suitable for an application. If the application is potable water, this much oxidation will probably lead to pitting attack.

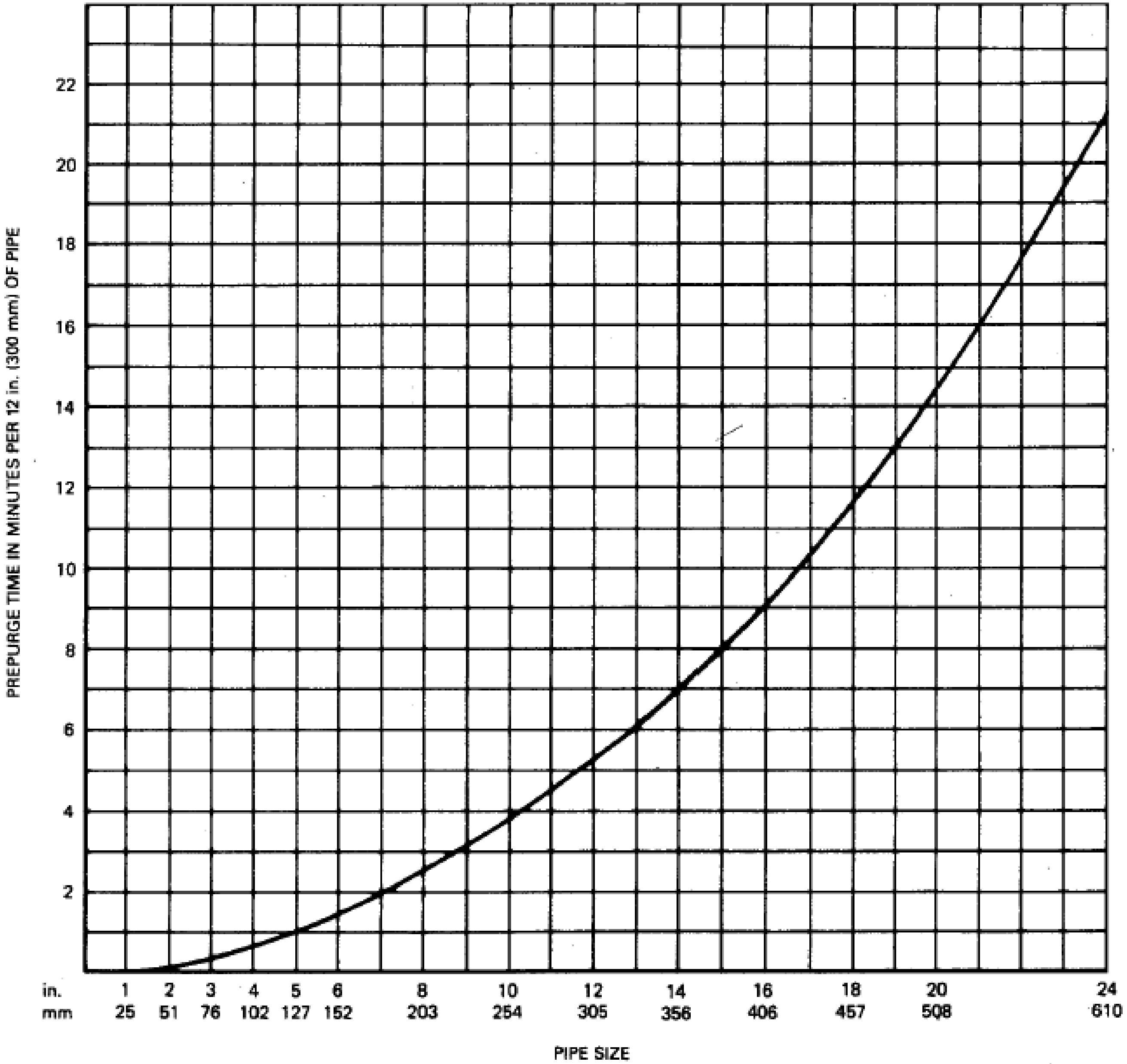
You can do the same with GTAW but not reliably unless the process is automated.

Origins of PFI ES-50

The other approach to protecting the root surface from oxidation is to replace the air inside the pipe with inert gas, usually argon. This is commonly referred to as "**purging**."

The techniques for doing that are described well in AWS D10.11, *Guide for Root Pass Welding of Pipe Without Backing.* It suggests that 5 volume changes is sufficient and provides the following chart.

At 50 CFH, the time required to purge NPS 12 pipe is about 5-1/2 minutes per foot of pipe length. That would be about 3-1/2 hours for a 40 foot length of pipe.



Prepurge time for 12 in. (300 mm) of pipe at a flow rate of 50 CFH (24 liters per minute)

To calculate the prepurge time for any length of pipe, multiply the value obtained from the chart by the length of pipe.

Example: Find time required for prepurging of 200 ft (60 m) of 5 in. (127 mm) pipe. From chart at 5 in. (127 mm) pipe size, get one min per 12 in. (0.3 m) of pipe; hence, 200 ft (60 m) = 200 minutes or 3 hours 20 minutes.

Origins of PFI ES-50

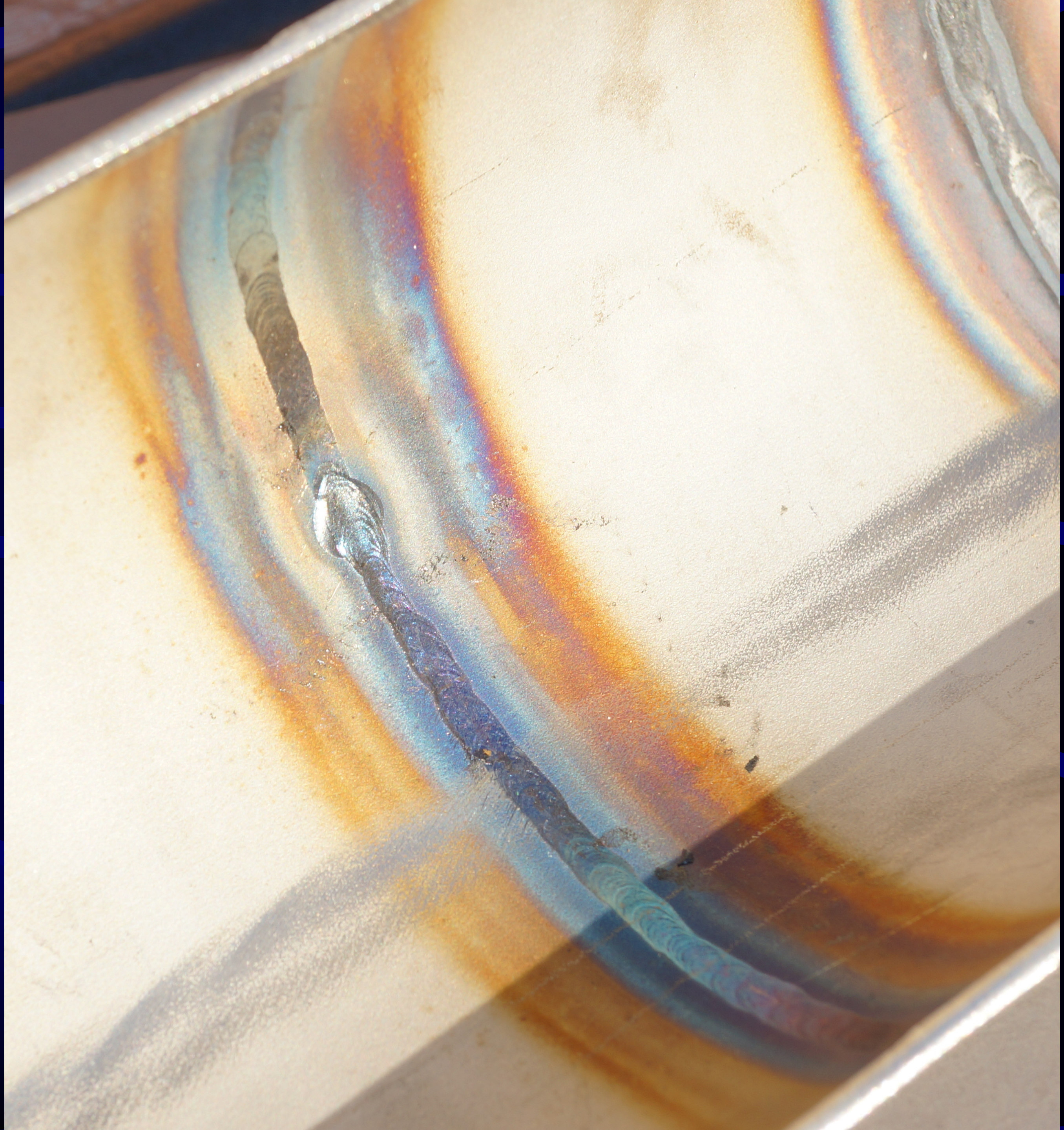
Following D10.11 does not guarantee that the weld surface will be free of oxides.

- Purge gas flowing at high velocity through a gas-permeable (i.e. rubber) hose or a fitting that is not tight will aspirate air into the gas stream.
- Moisture in the pipe will cause discoloration. Moisture can come from dust that has accumulated in the pipe.
- Surface contaminants like cutting fluids and oil from air-powered grinders will oxidize on the surface.

Origins of PFI ES-50

If a contractor follows AWS D10.11 to satisfy a specification requirement that stainless steel piping be purged, he will have met the specification simply by following D10.11. Yet the weld surface may be heavily oxidized and not suitable for the intended application.

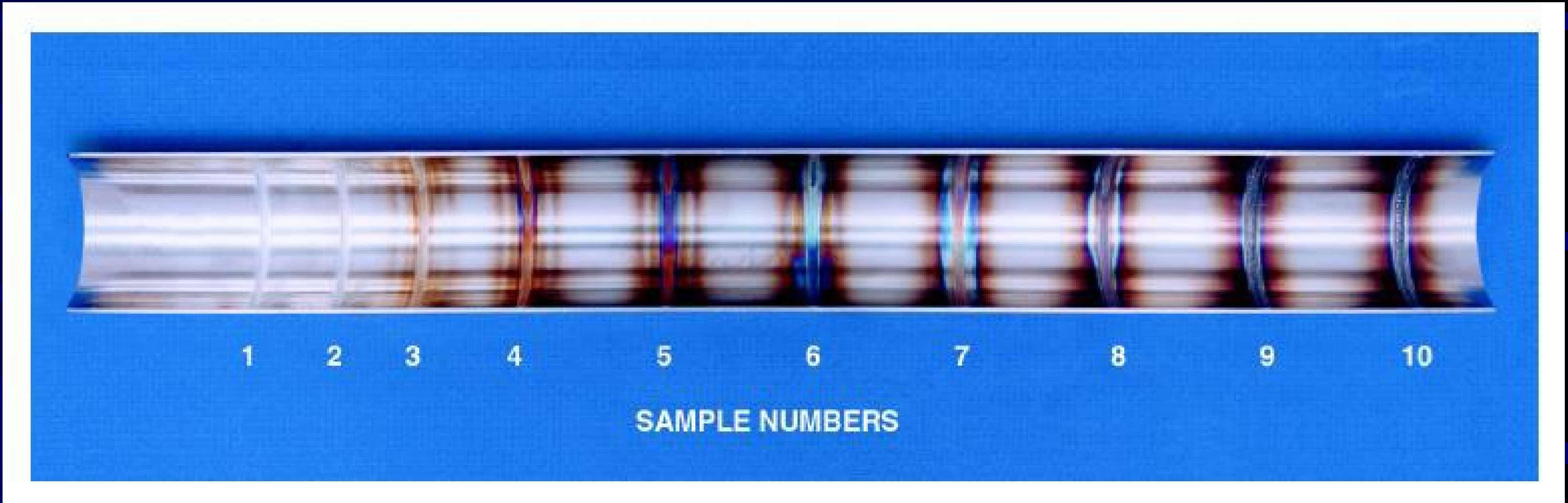
This weld <u>was</u> purged. If all the specification requires is that the pipe be purged, this meets that requirement.



Origins of PFI ES-50

AWS D18.1 and ASME Bioprocessing Engineering addressed the issue of “discoloration” of stainless steel decades ago by publishing pictures showing various levels of discoloration.

AWS D18.1



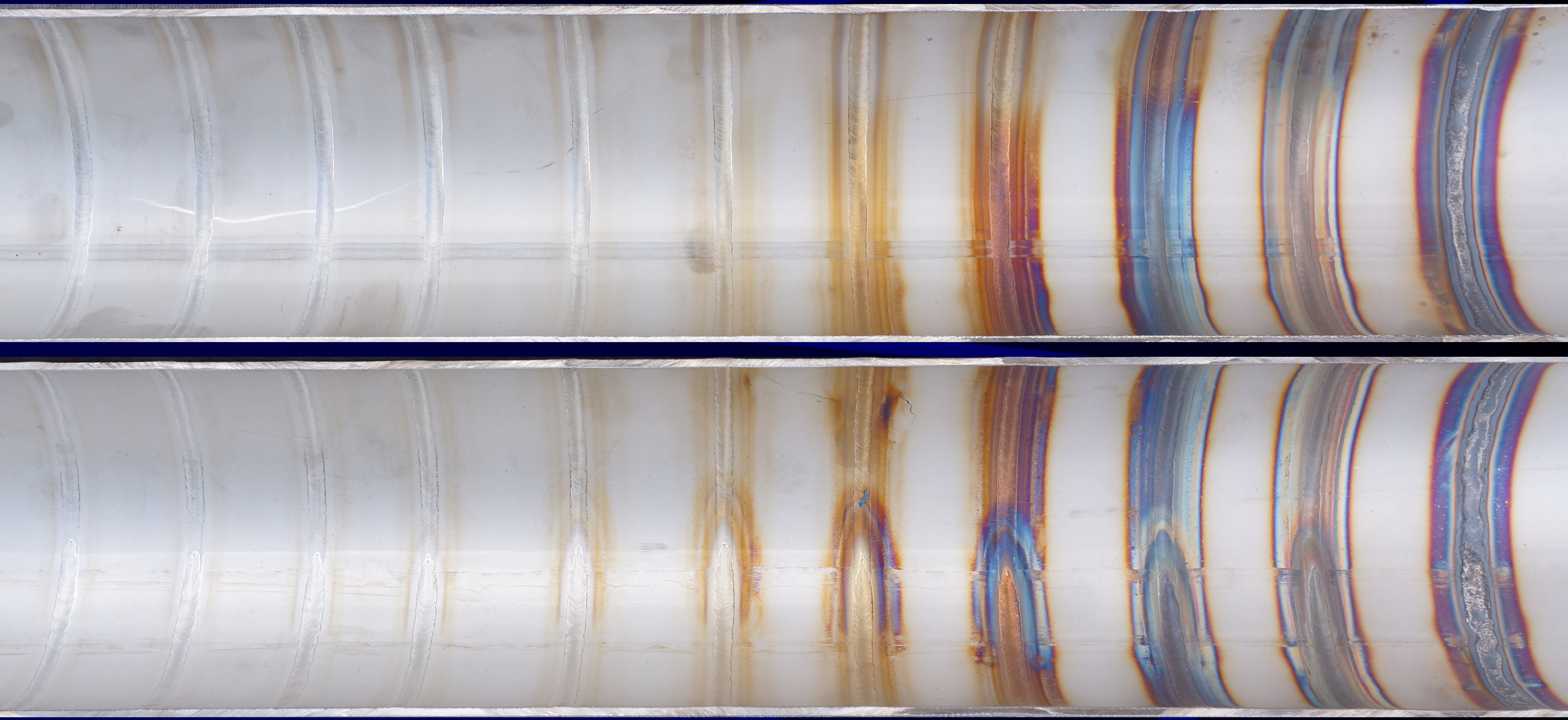
Origins of PFI ES-50

For a piping fabricator or erector installing industrial piping, these standards presented three issues:

1. The samples showing the levels of discoloration were made on tube that had a polished ID surface rather than the pickled surface found in industrial piping.
2. The standards tied the discoloration to the ppm oxygen level in the purge gas.
3. There was no guidance on selection of an acceptable level of discoloration for a variety of service conditions

Development of PFI ES-50

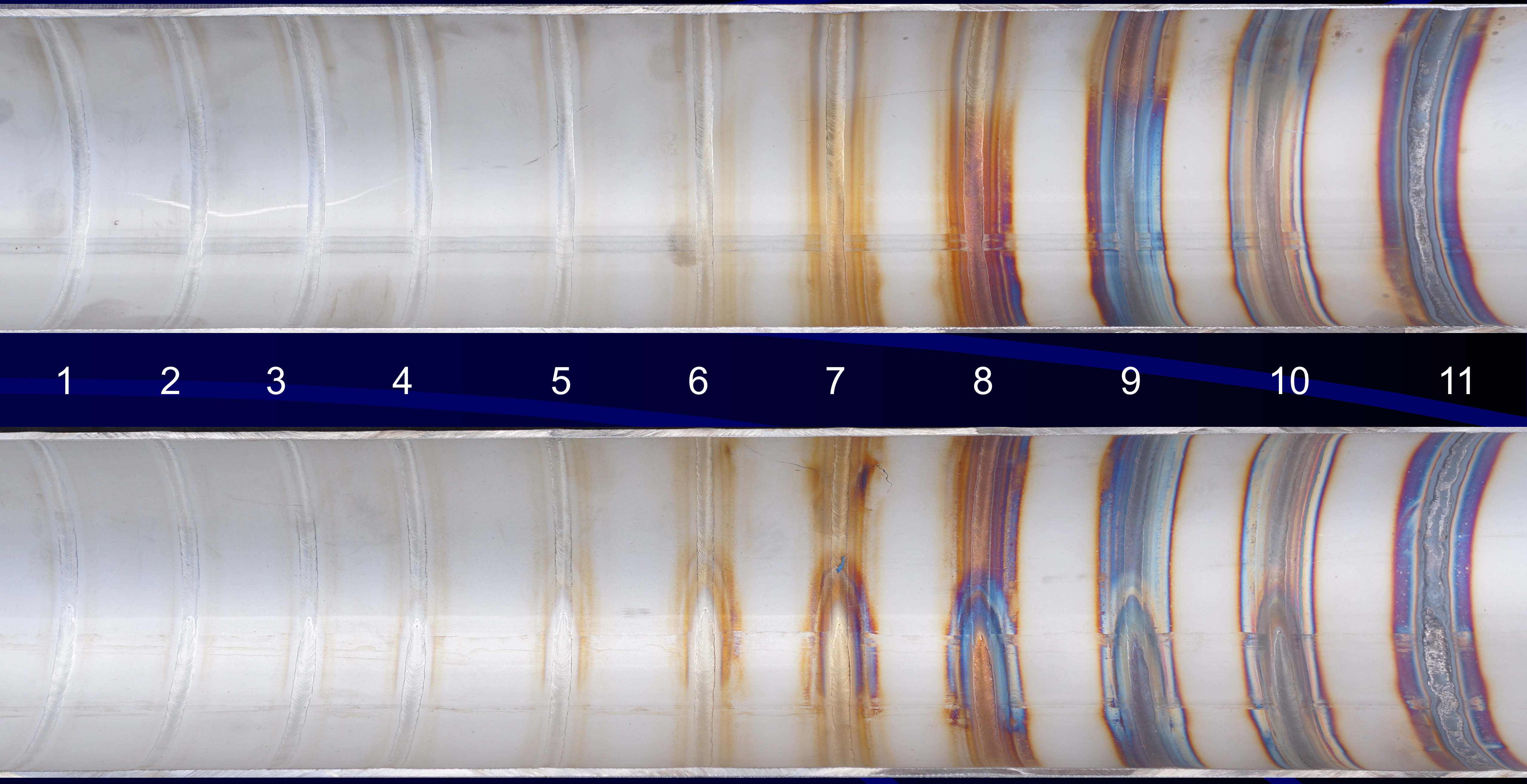
We used ASTM A-270 Type 304L stainless steel tube 3 inch OD with a wall thickness of 0.065 with a pickled mill finish. To ensure uniformity of weld appearance, an orbital GTAW welding head was attached to the pipe and set up so that the current would melt through and create a liquid surface as the head proceeded around the pipe. While we started with separate argon and oxygen supplies, we found that controlling the oxygen at the PPM level was reliable using argon and an argon 2% oxygen.



The oxygen concentration low was 10 ppm high was 2%

Development of PFI ES-50

Rather than provide a “ppm” criteria, ES-50 identifies the discoloration by number and asks the engineer to select and specify the discoloration that is acceptable for his application **by number** and leave it up to the fabricator or contractor to figure out the most economical way to meet the selected discoloration.


1 2 3 4 5 6 7 8 9 10 11

Development of PFI ES-50

The standard also points out that, to get less discoloration, one has to purge for a longer time, so purchaser should expect higher cost of fabrication and installation for less-discolored surfaces.

Technical Background of PFI ES-50

What causes the change in colors?

The thickness of the oxide layer. Incident light reflects off the metal surface. When the oxide is thin, all the light is reflected so stainless steel looks white. When the oxide film gets thicker, light is absorbed by the oxide layer except for yellow; as the oxide thickness increases, the yellow becomes darker, then it turns successively orange, brown-red, blue, purple, brown, grey until, ultimately, it forms an opaque grey/brown film.

Technical Background of PFI ES-50

How do the oxide layers affect corrosion resistance?

The initial oxides form as iron diffuses to the surface forming iron oxides of hematite and magnetite. These oxides reflect yellow light. Chromium remains below the surface, ready to maintain the chromium oxide barrier that keeps stainless steel stainless. This is true up to about color number 6.

Technical Background of PFI ES-50

Eventually chromium diffuses to the surface and begins to oxidize. The layers turn orange, then brown-red then blue. This lowers the chromium concentration in the layer beneath the oxide layer.

As more chromium diffuses to the surface, the oxide turns purple, then brown then grey, and a chromium-depleted layer forms beneath the oxide layer.

Technical Background of PFI ES-50

- As the oxide layer thickens, it cracks, allowing corroding media to attack the diminished substrate beneath the oxide layer causing pitting in mild environments.
- Strong acids, on the other hand, will dissolve these oxide layers uniformly, restoring the stainless steel to its original corrosion resistance.
- Nonconductive fluids (hydrocarbon fuels and similar), , generally do not cause corrosion unless they are contaminated by sulfides, chlorides and similar.

Service condition	Discoloration ID Number
Dry air or other noncorrosive gas	11
Oil, gasoline, diesel fuel and other nonconductive organic liquids:	4
Strong acids (Low pH solutions):	7
Caustic (high pH) solutions:	7
Potable water in regular service, usually flowing[7]:	4
Potable water that will be stagnant[8]	2
Bioprocessing: according to ASME's Bioprocessing Engineering Standard:	3

Implementing PFI ES-50

Engineers using PFI ES-50 need to evaluate the service conditions. There are many reasons for selecting stainless steel:

- Corrosion resistance (e.g. when handling strong acids)
- Corrosion resistance (to keep the product from contamination)
- Toughness for cryogenic applications

Implementing PFI ES-50

Engineers need to look at previous use of stainless steel in their application to see what any precedent is. If some level of discoloration has been found to be work reliably, select the appropriate color number and specify that PFI ES-50 be followed and that color number.

Let the contractor or fabricator figure out how to get there.

www.pfi-institute.org

PFI Standard ES-50
June 2020

INTERNAL OXIDATION FOR PIPING WELDS

Prepared by

Pipe Fabrication Institute Engineering Committee

All PFI Standards are advisory only. There is no agreement to adhere to any PFI Standard and their use by anyone is entirely voluntary.