PFI Standard ES-50
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INTERNAL OXIDATION FOR PIPING WELDS

Prepared by

Pipe Fabrication Institute Engineering Committee

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1. Scope

1.1. This standard was developed to serve as a simple means of specifying the acceptable level of discoloration of the root side of stainless steel pipe welds. It does this using photographs of root-side surface oxidation of stainless steel welds made using GTAW and purge gas with various oxygen levels. It also gives general guidance on the level of root surface discoloration that can be tolerated for some service conditions. This standard may be applied to welds made using any welding process. While this standard refers to pipe, it is also applicable to welds made using tube.

2. Background

2.1. When welding stainless steel and nickel alloy piping using an open root or consumable insert, the root side of the joint (i.e., the inside surface of the pipe at a weld) must be protected from the oxygen in the atmosphere, otherwise the liquid weld metal will oxidize badly creating a surface that is not only discolored, but is also quite rough. See Figure 1. This roughness and discoloration will reduce the corrosion resistance of the metal at the weld.

2.2. Roughness occurs because the chromium in stainless steel oxidizes, forming chromium oxide. Chromium oxide has a melting point that is well over 4,000°F (2,200°C) and that is well above the 2,600°F (1,425°C) melting temperature of stainless steel. As a result, chromium oxide forms as a solid material on the liquid weld pool. Because the oxide is a solid, it does not form a smooth surface; instead, it forms the coarse, rough surface shown in Figure 1.

3. Prevention of Oxidation

3.1. The root surface must be protected from the oxygen in the atmosphere during welding to prevent this oxidation. This is done by displacing the air inside of the pipe before welding is started using argon or, for some stainless steels, nitrogen gas. This process is known as "purging," and the inert gas is referred to as a "backing gas." Other techniques for affecting the weld surface such as flux-coated filler metal or application of fluxing agents to the root side of the joint before assembly are outside the scope of this document.

3.2. The discoloration obtained may be affected by factors other than oxygen such as:

3.2.1. Moisture in the pipe.

3.2.2. Contaminates such as hydrocarbons and dirt on the interior surface. The inside surfaces of the pipe near the weld should be carefully cleaned before fit-up.

3.2.3. The metal surface finish roughness.

3.2.4. Welding process

3.2.5. Backing gas composition and purity

3.3. Techniques for purging are beyond the scope of this document[1]. However, it is important to note that the air in a pipe assembly needs to be replaced many times to drive the oxygen down and reduce discoloration. The right column of Table 1 shows the purge time needed to achieve the parts-per-million (ppm) concentration of oxygen shown in the left column for one cubic foot of volume. The time required to achieve a given oxygen level increases exponentially as the level of oxygen is reduced; accordingly, purchasers should recognize that reducing the level of discoloration will increase the cost of fabrication.

4. Selecting and Specifying an Appropriate Level of Discoloration

4.1. The contract should specify the ID number of the color of discoloration shown in Figures 1 and 2. Using the ID number is important since welds on stainless steel can be made successfully using the GMAW process and achieve a color ID around 8 without purging the pipe. Also, a specific level of discoloration can be reached at a higher oxygen level by using a small amount of hydrogen in the backing gas.

4.2. When welding stainless steel, purging of the root surface may be necessary to make a weld that can be inspected. The surface of the weld shown in Figure 1 is so rough and coarse that one cannot determine if the weld is or is not fully penetrated. Further, volumetric nondestructive examination would be indeterminate with such a surface. Reducing the oxygen over the weld pool to 2% is sufficient that the

[1] See AWS D10.11, *Guide for Root Pass Welding of Pipe Without Backing*

resulting weld surface, although heavily oxidized, can be visually and volumetrically examined successfully.

4.3. It should be noted that socket welds will also discolor during welding even though the weld will not normally penetrate the interior surface of the pipe. Discoloration acceptance criteria apply to socket weld interior surface also; however, care should be taken in evaluating socket weld discoloration as noted in Figure 4.

5. The Origins of Weld Discoloration "Heat Tint"

5.1. Whether or not discoloration is harmful depends on the service environment. The polychromatic discoloration evident in Figures 2 and 3 is caused by light reflection interference phenomenon. The thickness of the oxide layer determines the color of light that is reflected from the oxidized surface. The thinnest oxide reflects a pale yellow color; 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. As the oxygen present during welding increases, the oxide film thickness will increase, and the discoloration shown in Figures 2 and 3 follow the above progression of color changes.

5.2. Evaluation of the composition of the oxide layers [2]show that its composition changes with thickness. As the oxides form, iron in the stainless steel oxidizes first, and the yellow discoloration one sees is iron oxide. The chromium in the metal beneath this layer is unaffected, and that thin iron oxide layer actually decreases the pitting potential of the stainless steel[3]. As the oxide layer thickness increases, chromium begins to diffuse to the surface, and darker oxide films form; they are mainly chromium oxides. This diffusion of chromium depletes the chromium from the material just beneath the oxide layer[4] reducing its corrosion resistance. Because iron-based oxide is volumetrically larger than the metal from which it is formed, oxide layers are in a state of compression. As the oxide layer thickness increases, these compressive stresses increase and cause the oxide to crack. These cracks allow the corroding media to reach the chromium-depleted layer just beneath the oxide layer, setting up conditions for crevice corrosion. This leads to pitting beneath the oxide layer, particularly in the presence of chlorides. However, in the presence of strong acidic solutions such as a 10% sulfuric or nitric acid[5] or a 3.5% NaCl solution[6] at a pH of 1, the oxide layers and chromium-depleted steel underneath will be dissolved, and the steel will suffer from general corrosion rather than pitting attack. Stagnant potable water, on the other hand, will cause pitting of thick oxide layers .

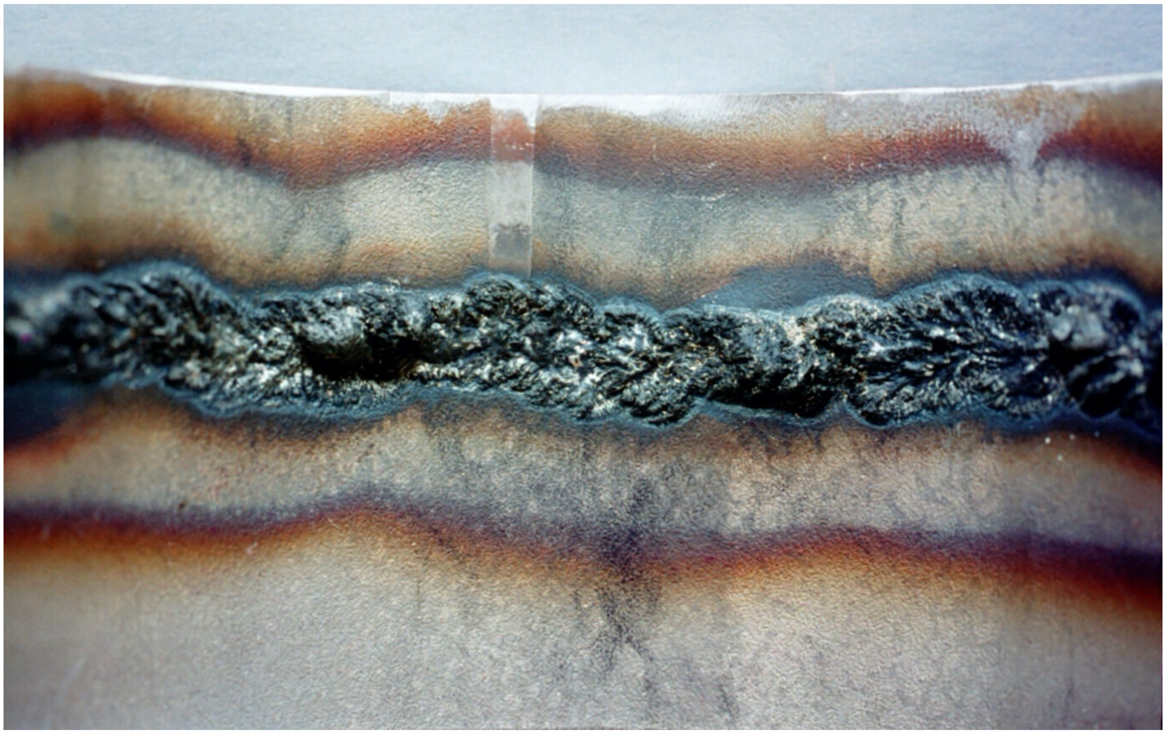
5.3. Table 2 gives suggested levels of discoloration for various services based on generally available resources such as those shown in the footnotes. Trace levels of chemicals, fluid flow rates, temperature, absence of oxygen and many other factors can have a huge effect on the corrosion-resistance of materials and welds. Since only the purchaser and the design engineer have access to all the information about the service conditions that affect corrosion, only they can select an appropriate level of discoloration; accordingly, the PFI is not responsible for the selection of an appropriate level of discoloration.

6. Reference Photographs

6.1. The discoloration levels shown in Figures 2 and 3 were prepared by making eleven autogenous welds on a 3-inch (50 mm) 304L stainless steel tube 0.049 inches thick. The welds were made using an automatic orbital tube welder set so that the liquid weld pool would penetrate through the pipe wall and be exposed to the gas inside the pipe. To provide varying amounts of oxygen in the backing gas, argon with 2% oxygen was metered into a primary high-purity argon backing gas. The oxygen level was measured with a calibrated, high-sensitivity oxygen meter. Color ID 11 in the photos was made using argon with 2% oxygen.

[2] Influence of surface treatment on Corrosion Resistance of Cr-Ni Steel, T. Brajkovic, I Juraga and V. Simunovic, *Engineering Review*, Volume 33, Issue 2, 129-134, 2013
[3] Role of heat tint pitting on corrosion of 304 austenitic stainless steel in chloride environment, F Elshawesh and E Eljoud, *Petroleum Research Center*, Tripoli, Lybia
[4] Heat Tints on Stainless Steel Can Cause Corrosion Problems, A. Tuthill and R Avery, *Material Performance*, February 1999.
[5] Effects of Oxidation on Corrosion Behavior of Austenitic StainlessSteel, Kumar, Kain, Banerjee, Maniyar, et. al, *Advanced Materials Research*, Volumen 794, pp 598 to 605
[6] Influence of Heat-tinted Surface Layers on the Corrosion Resistance of Stainless Steel, T. Von Moltke, P. C. Pistorius and R. E. Sandenbergh, *Proceedings of the First International Chromium Steel and Alloys Congress*, Volume 2, 1992, pp 185 to 195.

Figure 1

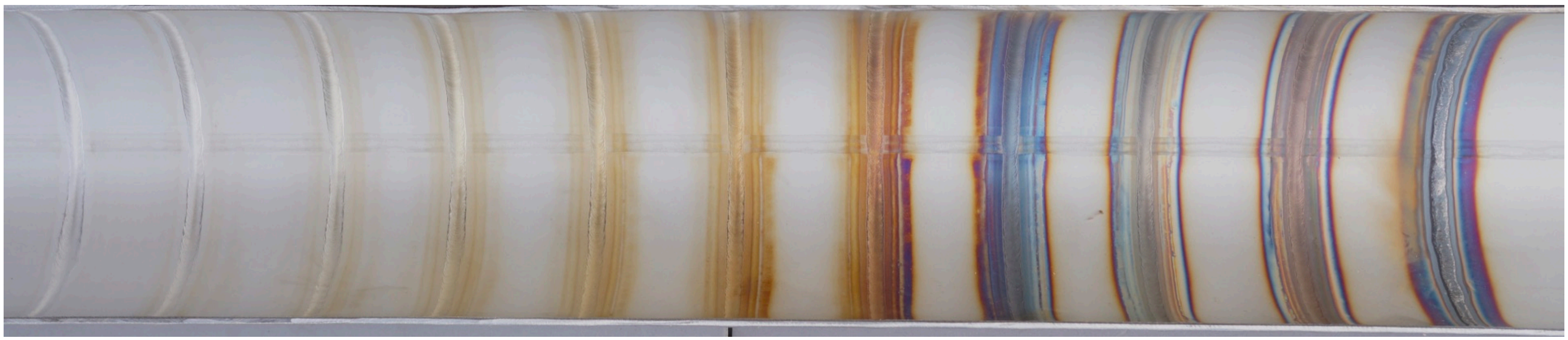


This photograph shows the root side of a weld that was made using GTAW open root with the root side exposed to air. Note the coarse, irregular surface.

Figure 2

Weld Discoloration Levels on the Inside of 304L tube

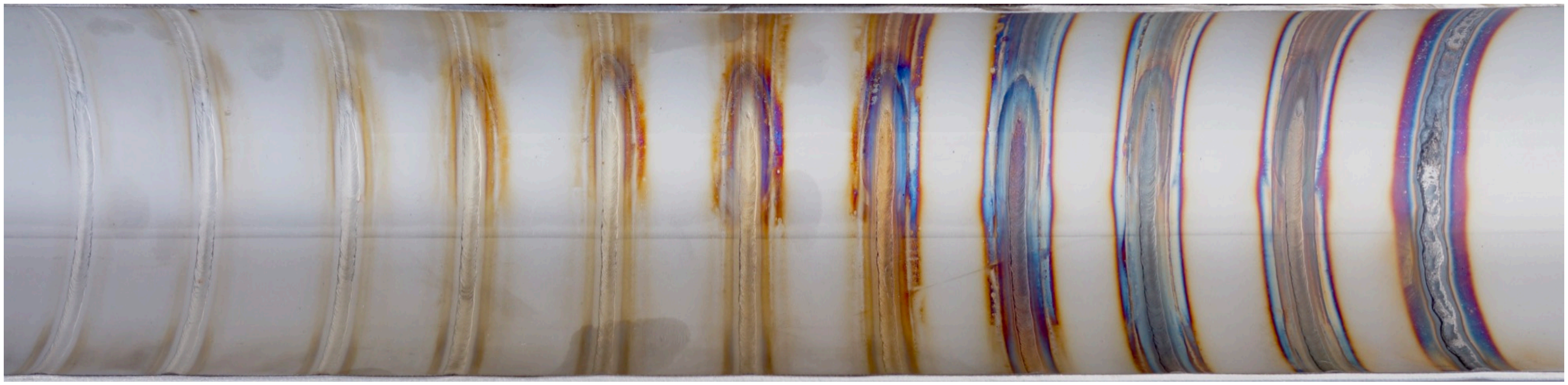
NOTE: The user is cautioned that electronic versions or photocopies of these acceptance criteria should not be used for evaluation of sample or production welds since subtle differences in color can influence weld acceptability. Figures 1 and 2 are available from PFI as a stand-alone printed document suitable for use as reference standards



ID: 1 2 3 4 5 6 7 8 9 10 11

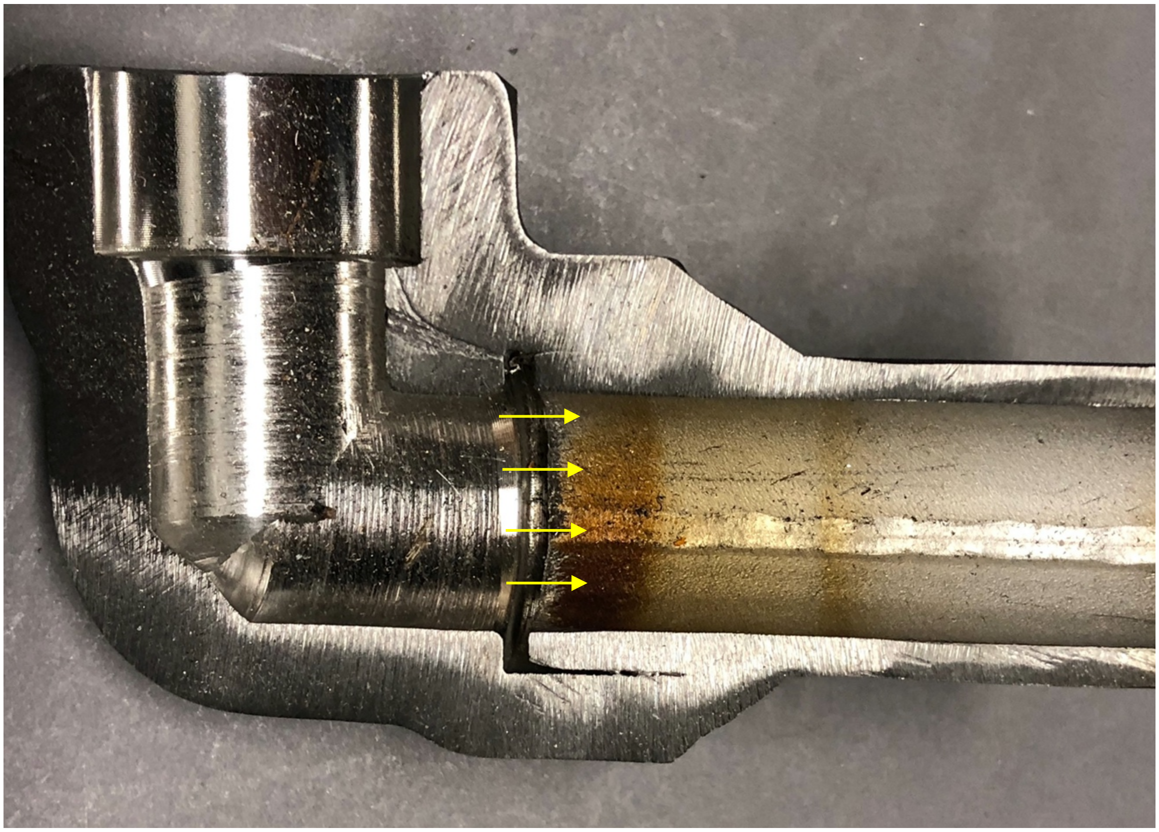
Figure 3

Weld Discoloration Levels on the Inside of 304L Tube Showing Weld Overlap Zones



ID: 1 2 3 4 5 6 7 8 9 10 11

Figure 4
Socket Welds



While the above may seem severely discolored, discoloration of the pipe that is well inside the socket is irrelevant since it does not lead to the outside world. The discoloration that should be judged is the surface from the weld away from the fitting shown by the yellow arrows.

Table 1

Purge Times

PPM	Minutes
1	**14.2**
10	**11.9**
50	**10.0**
100	**9.2**
500	**7.3**
1000	**6.4**
5000	**4.5**
10000	**3.6**
25000	**2.6**
100000	**1.0**
210000	**0.0**

The right column shows the theoretical time required to purge one cubic foot of air (1728 in^3) down to the parts per million (PPM) oxygen shown in the left column using argon at a flow rate of 50 cubic feet per hour.

Table 2

Suggested Levels of Discoloration for Some Applications

See cautionary notes in paragraph 5.3

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**

THE INFORMATION CONTAINED IN THIS DOCUMENT IS BASED ON GENERALLY AVAILABLE INFORMATION AND IS INTENDED EXCLUSIVELY FOR EDUCATIONAL PURPOSES. ONLY THE PURCHASER AND HIS DESIGN ENGINEER HAVE ACCESS TO ALL THE INFORMATION ABOUT SERVICE CONDITIONS THAT AFFECT CORROSION, AND ONLY THEY CAN SELECT AN APPROPRIATE LEVEL OF DISCOLORATION. PFI MAKES NO WARRANTIES OR REPRESENTATIONS WITH RESPECT TO THE INFORMATION, OR THE PRODUCT/MATERIALS DESCRIBED HEREIN. PFI EXPRESSLY DISCLAIMS ALL EXPRESS AND IMPLIED WARRANTIES AND CONDITIONS.

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7 Heat-tinted Stainless Steel Welds – Guidelines for Acceptance, L. H. Boulton, R. E. Avery, Stainless Steel World, April, 2004

8 Allowing potable water to set stagnant in 300 series stainless steel piping for more than a day is generally not a good idea since that risks initiating pitting attack at any flaw or contaminant present on the pipe surface. On the other hand, water that has been treated with appropriate corrosion inhibitors such as those used in closed loop cooling systems can remain stagnant for much longer times.