

# White Paper

## Are you using tubing and fittings that will fail the required ASME BPE Testing?

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### EXECUTIVE SUMMARY

The 2019 edition of the ASME Bioprocessing Equipment Standard now requires that all austenitic stainless steel tubing must be capable of passing a weld-decay corrosion test and intergranular corrosion test. This testing is to ensure that tubing and components made from tubing are properly welded and heat-treated to provide optimum corrosion resistance. The weld decay test, often referred to as S7 test, is used to detect the presence of delta ferrite formed during solidification when welding austenitic stainless steel materials, such as 304L and 316L. The presence of delta ferrite increases the materials susceptibility to corrosive attack. This paper explains why the S7 test has been added to the standard and the methodology of conducting the test. In addition, this paper shows the actual test results from tubing and tubular components from tubing that passes S7 compared to tubing that fails S7 testing. Tubing produced by many of the low cost producers fail the S7 test. The use of these tubes for fittings and process lines is not permitted under ASME BPE after December 1 2019.

### BACKGROUND

Effective with the 2019 edition of the ASME Bioprocessing Equipment Standard a new requirement for austenitic stainless steel tubing will be implemented. That requirement can be found in Part MM – Metallic Materials of Construction. It will require that welded tubes supplied to the industry be capable of passing a weld decay corrosion test and an intergranular corrosion test, as described in ASTM A249 and A270, respectively. These tests are being implemented to ensure that tubes, and the components manufactured from them, have been properly welded and heat-treated to provide optimum corrosion resistance in service. The requirement is stated as follows:

*Austenitic stainless steel tube shall be capable of passing the weld decay test in ASTM A249/A249M, Supplement S7 and either the Intergranular corrosion test in ASTM A270/A270M, Supplement S1 or ISO 3651-2 Method B.*

The ASTM A249/A249M Supplemental Requirement S7 is a weld decay test that is used to detect the presence of delta ferrite formed during solidification when welding austenitic stainless steel materials like type 304, type 304L, type 316 and type 316L. (Note: The BPE requirement is only applicable to the longitudinal seam welds made during the original manufacture of tubing. Application of these tests to other components is at the discretion of the user.) It is not applicable to the more highly alloyed materials like 317L, 904L, or the super-austenitic materials having molybdenum levels of nominally 6%, and higher alloys. In these alloys the nickel content is adequate to suppress the formation of delta ferrite, and the higher molybdenum levels help prevent halide ion ( $F^-$ ,  $Cl^-$ ,  $I^-$ ,  $Br^-$ ) pitting attack..

The presence of delta ferrite is a function of the chemical composition of the steel and the cooling rate of the molten weld puddle through solidification. It is a magnetic constituent in the steel microstructure and is more sensitive to corrosive attack in reducing environments with acidic pH values

The amount of ferrite present in a given metal composition can be predicted by a calculation known as a “Ferrite Number”. The higher the number, the more likely the composition will yield ferrite. The calculation is based on equilibrium (infinitely slow) cooling and so is not a precise real world prediction, but is more of a relative index number to compare various compositions. It is based on the relationship of the levels of those elements that tend to promote the formation of ferrite to the levels of those that promote the formation

of austenite. The number is typically calculated based on the levels of chromium, silicon, molybdenum, columbium (ferrite promoters), carbon, manganese, nickel, nitrogen and copper (austenite promoters). The DeLong Diagram and the Welding Research Council (99) Diagram are two commonly used methods for determining ferrite number. In Europe, the use of the Basel Norm is more common.

The presence of delta ferrite increases the materials susceptibility to corrosive attack in reducing atmospheres, such as in hydrochloric acid, which is widely used in pharmaceutical manufacturing processes.

The ASTM A249/S7 Weld Decay Test is an accelerated corrosion test that can typically be completed in 2 hours or less for 316 type stainless steels. It involves a solution of 50% by volume of hydrochloric acid in water. A test coupon approximately 2 inches long x approximately 1.25 inches wide is measured at several points along its length in both the base metal and along the longitudinal seam weld. The sample is then immersed in the boiling acid solution for whatever time is required to reduce the base metal wall thickness by  $50\% \pm 10\%$ . The sample is then cleaned and dried and the thickness values are measured at the same locations as before immersion. The test result is then reported as a ratio of the change in thickness of the weld to the change in thickness of the base metal.

$$R = (W_b - W_a) \div (B_b - B_a)$$

An ideal ratio of 1.00 would indicate that there is no significant difference between the weld metal and the base metal.

A ratio of less than 1.00 indicates that the weld is more resistant to corrosion than the base metal.

A ratio of greater than 1.00 indicates that the weld is more susceptible to corrosion than the base metal.

ASTM A249/S7 defines a maximum ratio of 1.25 as being acceptable.

The formation of delta ferrite is also dependent on the solidification and cooling rate of the molten metal. Those welding processes that have faster solidification rates, like laser welding are less likely to form delta ferrite than are more traditional welding processes like GTAW. Laser beam welds exhibit smaller heat affected zones and smaller volumes of molten metal, and therefore typically exhibit better corrosion resistance. Typical Weld Decay Test results for laser welded and solution annealed tubes range from 0.85 to 1.03. That said, an effective solution anneal heat treatment can yield GTAW welds that provide Weld Decay ratios between 0.90 and 1.25.

The ASTM A262 Practice E test referenced in ASTM A270 Supplementary Requirement S1 is an intergranular corrosion test. It is used to detect sensitized structures that can form after improper heat treatment or after extended exposure to temperatures in the range of about 675° - 1,000° F (357° - 538° C). Sensitization occurs when intermetallic precipitates such as chromium carbides are formed along the metal grain boundaries. When the chromium is bonded with carbon in these precipitates it is no longer available to form the passive chromium oxide layer that provides corrosion resistance.

In this test a flat sample is cut and prepared and is immersed in a boiling bath of copper-sulfate and sulfuric acid for 15 hours. After exposure the sample is bent around a mandrel and the sample is visually examined for any cracking. The presence of cracks after bending constitutes failure. The results are reported as pass or fail. Given the predominance of modern low carbon grades of austenitic stainless steels such as 316L, the occurrence of sensitization in either manufacture or in service has been greatly diminished and test failures are rare.

Weld Decay testing of competitive “bargain brands” has shown that some producers fail to consistently meet the minimum requirements of the A249/S7 test. Weld Decay ratios exceeding values of 2.5 have been measured on some low cost tube and fittings. In some cases the weld has been completely dissolved in partial sections. Below are photos of S7 corrosion test results from samples of competitive off shore tubing and fittings



Fig. 1. Sample of a 1.00" 90 degree elbow as received. Note that it is certified as being BPE compliant as indicated by the ASME symbol stamp. Information identifying the manufacturer is blacked out.



Fig 2. Sample of a 1.50" Tee as received. Note that it is certified as being BPE compliant as indicated by the ASME symbol stamp. Information identifying the manufacturer is blacked out.



Fig. 3. Samples of 0.50" and 1.50" OD straight length tubing as delivered from the same supplier as the above fittings.

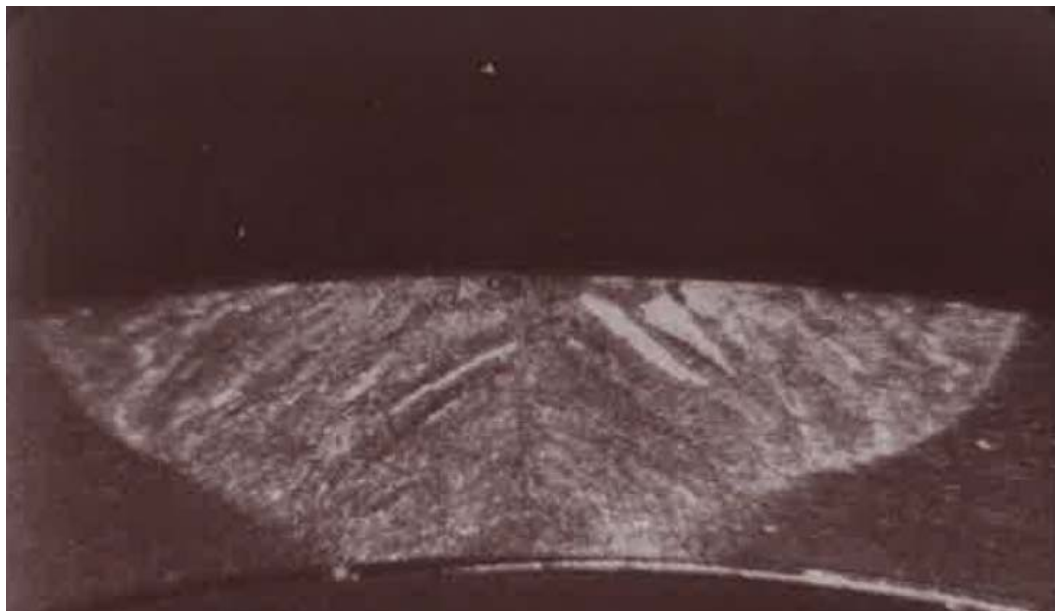


Fig 4. A metallurgical mount of the weld cross-section showed that the 1.00" elbow was manufactured by a TIG (GTAW) welding process. TIG welding is the most commonly used method of welding in tube manufacturing, but it is an older less robust process than is laser welding, resulting in a wider weld bead and larger heat affected zone. This weld bead shape is common in TIG welded tubes.



Fig 5. A metallurgical mount of the weld cross-section showed that the tube used to manufacture the 1.50" Tee was manufactured by a TIG (GTAW) welding process. This weld bead shape is common in TIG welded tubes.

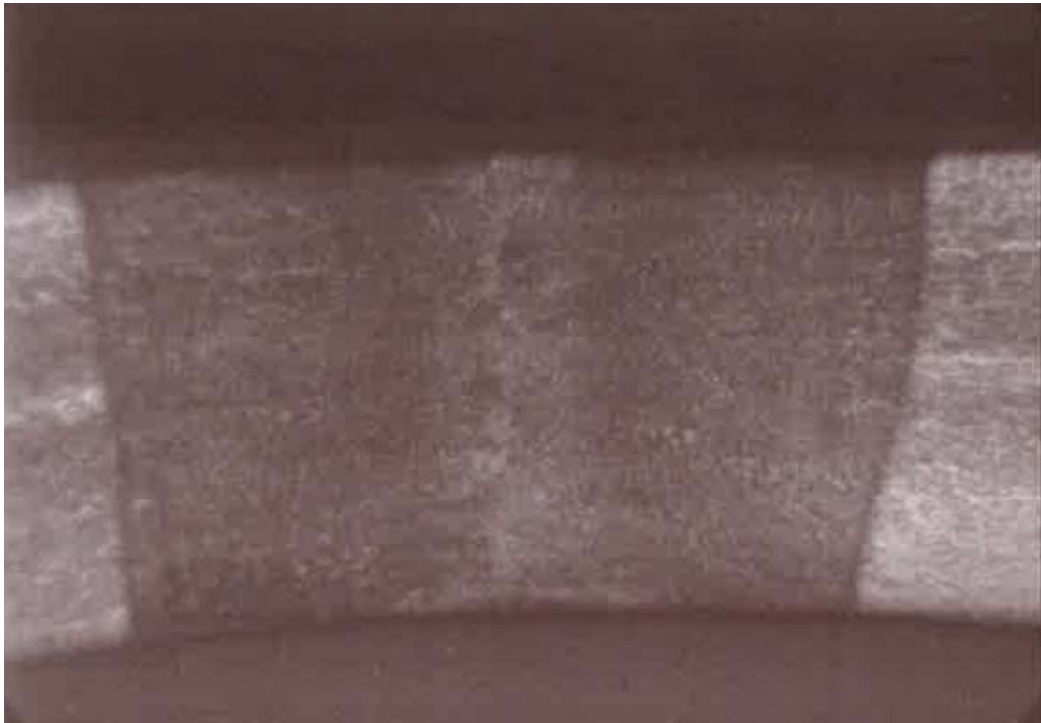


Fig. 6. A metallurgical mount of the weld cross-section of a sample of straight length 1.50" OD tube was manufactured by a TIG (GTAW) welding process. Note that this weld shape is significantly different than that in Fig. 4, which was produced by the same tube manufacturer. This weld bead shape is less common in TIG welded tubes than that shown in Fig. 4.



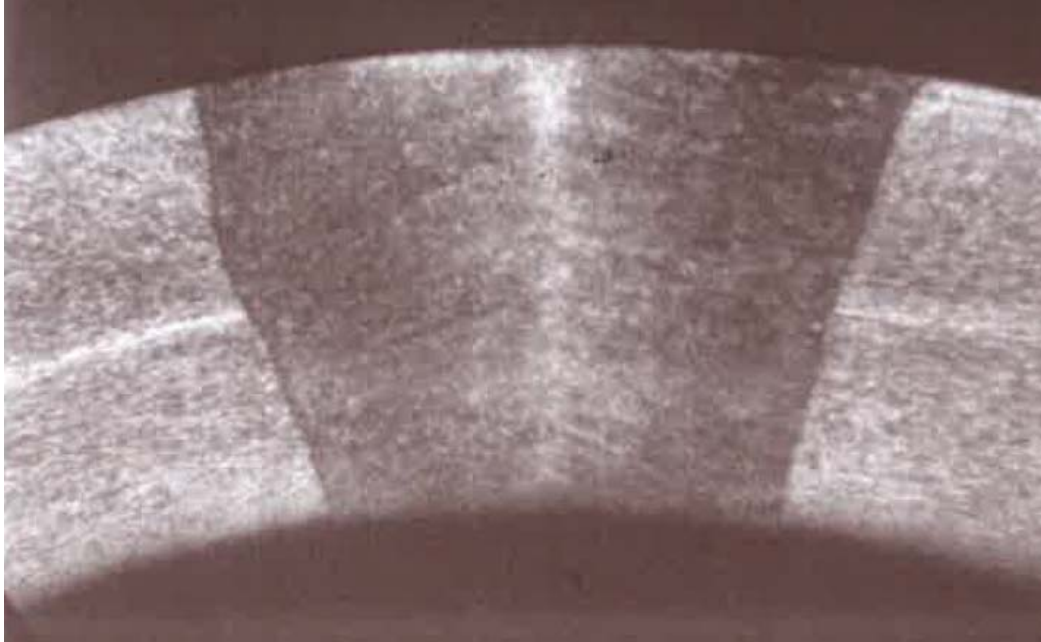


Fig 7. A metallurgical mount of the weld cross-section of a sample of straight length 0.50" OD tube was manufactured by a TIG (GTAW) welding process. Note that this weld shape is significantly different than in previous photos. It is less common in TIG welded tubes than that shown in Fig. 4. All samples are from the same tube manufacturer.

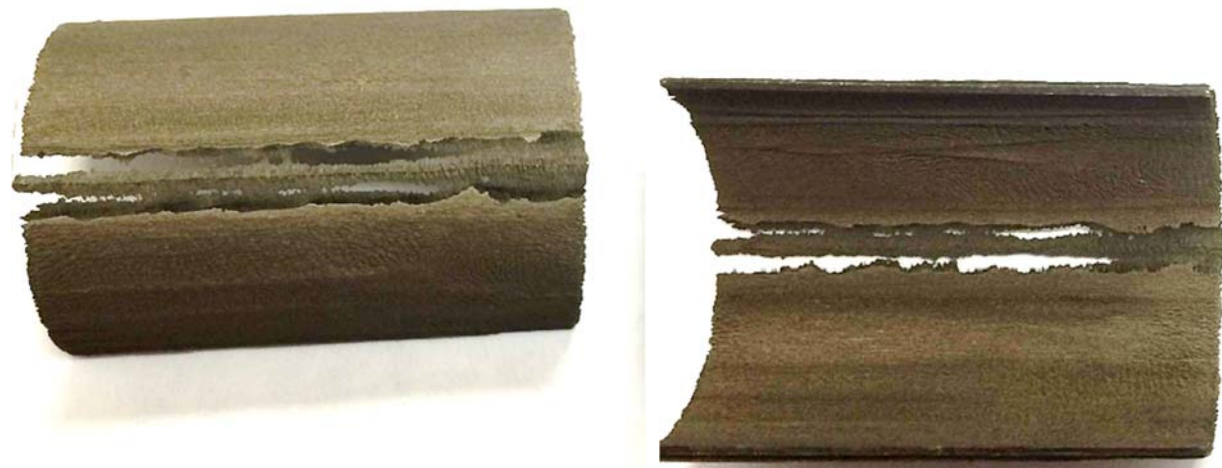


Fig.8. Results of ASTM A249/S7 weld decay corrosion test of the 1.00" elbow. Most of the longitudinal weld in this sample was consumed during the test. The OD surface is shown at left and the ID surface is shown at right.

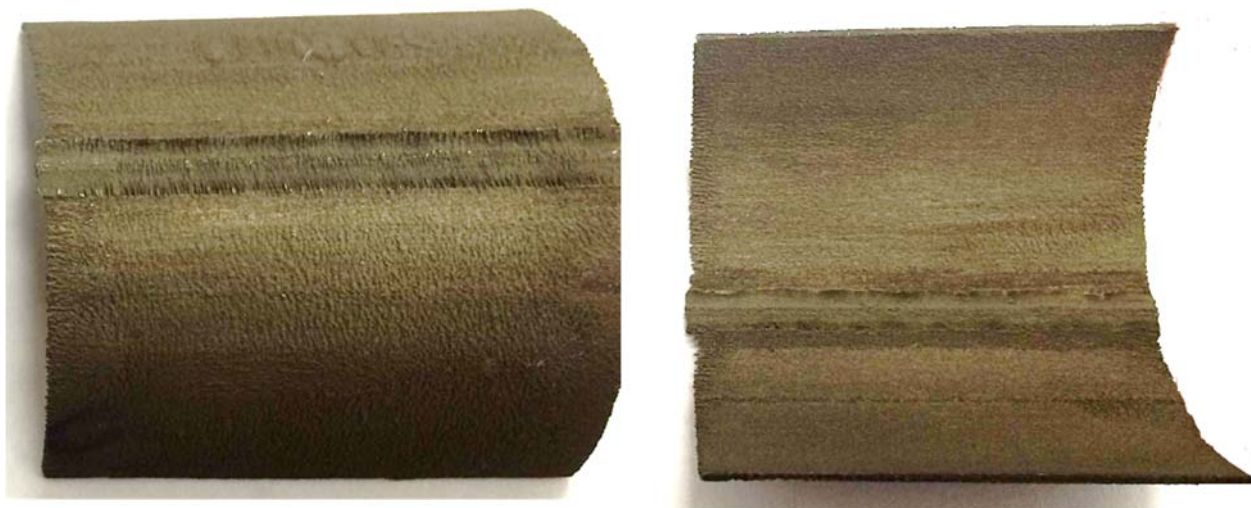


Fig. 9. Results of ASTM A249/S7 weld decay corrosion test of one leg of the 1.50" Tee. The longitudinal seam weld of the tube in this sample did not exhibit the same level of attack as in the elbow, but there was evidence of accelerated thinning along the weld fusion line / heat affected zone. This level of ditching along the edges of the weld indicates failure of the sample. Through-wall holes were noted in the weld heat affected zone, also constituting failure. The OD surface is shown at left and the ID surface is shown at right.



Fig. 10. Results of ASTM A249/S7 weld decay corrosion test of the 1.50" straight tube sample. The longitudinal seam weld of the tube in this sample did not exhibit the same level of attack as in the elbow, but there was evidence of accelerated thinning along the weld fusion line / heat affected zone. This level of ditching along the edges of the weld indicates failure of the sample. The base metal in this sample was reduced from 0.060" to 0.040" and the weld was reduced from 0.060" to 0.018" when the test was suspended. The resulting corrosion ratio was 2.13, well above the 1.25 maximum allowable. The OD surface is shown at left and the ID surface is shown at right.



Fig. 11. Results of ASTM A249/S7 weld decay corrosion test of the 0.50" straight tube sample. The longitudinal seam weld of the tube in this sample did not exhibit the same level of attack as in the other samples. The base metal in this sample was reduced from 0.063" to 0.024" and the weld was reduced from 0.061" to 0.032" when the test was suspended. The resulting corrosion ratio was 0.74, an acceptable result. The OD surface is shown at left and the ID surface is shown at right.

The following photos represent good laser welded and properly heat treated tubing after ASTM A249/S7 weld decay testing. Note that the weld metal was more resistant to attack than the base material as evidenced by the respective material thicknesses. Note that there is no localized ditching of the weld fusion line or the heat affected zone. This indicates that there is little to no alloy segregation in the weld metal as a result of the smaller volume of melted metal and the resulting shorter diffusion distances. The distribution of elements in the weld is as homogeneous as that in the base metal. A competitive sample is also shown. This sample was presented in the manufacturer's sales literature as being good welded tubing. The localized ditching along the fusion line of the weld suggests that the weld would be subject to localized attack by chloride bearing solutions of low pH.

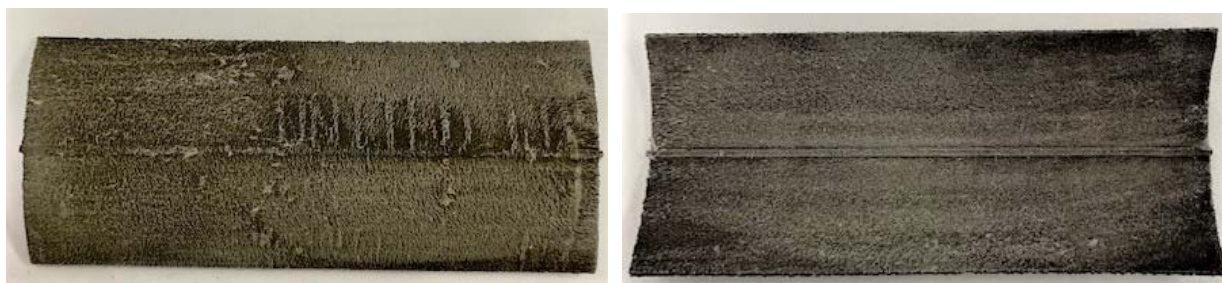


Fig. 12. Results of ASTM A249/S7 weld decay corrosion test of properly processed laser welded 2.50" X 0.065" 316L tubing, heat number A55P. The OD surface is at left and the ID at right. Note that the weld protrudes above the base metal on both surfaces indicating that the weld was more corrosion resistant than the base metal.

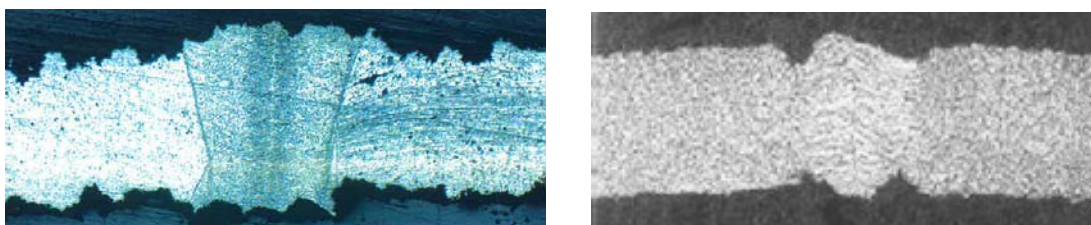


Fig. 13. On the left is a photomicrograph of the above sample showing a transverse section. Note the uniform attack across the base metal and weld on both the ID and OD surfaces. The corrosion ratio was 0.68.

On the right is a competitive laser welded tube section showing localized ditching of the fusion line and heat affected zone. The corrosion ratio of this sample was 1.25.



## **CONCLUSION**

While no accelerated corrosion test is representative of actual service conditions, the Weld Decay test and the Strauss test are quick and effective methods of evaluating whether a given tube has been properly manufactured (welded and heat treated) to provide optimal corrosion resistance. The Weld Decay test reveals the presence of delta ferrite, which is particularly subject to chloride ion attack. The Strauss detects sensitized microstructures. It was on this basis that the ASME Committee on Bio Processing Equipment adopted these testing requirements to ensure the use of properly manufactured welded stainless steel tubing.