

Considerations for Orbital Welding of Corrosion Resistant Materials to the ASME Bioprocessing Equipment (BPE) Standard

Barbara K. Henon, Ph.D., Arc Machines, Inc.

Presenter:



Barbara K. Henon

Academic Education:

1976 Ph.D. Biological Sciences, University of Southern California

1961 M.A. Zoology, Columbia University

1958 B.A. Zoology, Mount Holyoke College

Present Professional Position:

Manager Technical Publications, Arc Machines, Inc.

Standards Committees:

ASME Bioprocessing Equipment (BPE) Standard (Since 1989)

AWS D18 and D10 Committees

Liaison between ASME BPE and ASME B31.3 Process Piping

Presented on the *Stainless Steel America Conference 2008*

Considerations for Orbital Welding of Corrosion Resistant Materials to the ASME Bioprocessing Equipment (BPE) Standard

Barbara K. Henon, Ph.D., Arc Machines, Inc.

Keywords: orbital welding, 316L stainless steel, super-austenitic stainless steel, duplex stainless steel, ASME Bioprocessing Equipment (BPE) Standard, BPE, pharmaceutical industry piping, autogenous orbital welding, orbital welding with filler wire

Abstract

The ASME Bioprocessing Equipment Standard (BPE), first published in 1997, (current edition 2007) recommends the use of 316L stainless steel for tubing systems, system components and equipment for bioprocessing, pharmaceutical and personal care facilities where high purity and process control are essential. The BPE Subcommittee on Metallic Materials of Construction (MMOC) is currently working on a draft of a Part to be added to the BPE Standard which will expand the selection of acceptable metallic materials of construction to include 6 Mo super-austenitic stainless steels such as Al-6XN and some duplex stainless steel alloys. The MMOC Subcommittee will also define a method by which other metallic materials of construction may be submitted for consideration.

While 316L stainless steel tubing welded to the BPE Standard is routinely joined by autogenous orbital GTA welding, other alloys may require the addition of appropriately enriched filler material in order to maintain their corrosion resistance after welding. The use of insert rings higher in alloying elements than the base material has proven to be an acceptable method for welding of Al-6XN tubing of 0.065 inch wall thickness. This can be accomplished using orbital fusion welding equipment. The insert rings are manually tack welded in position and welded in an orbital weld head designed for autogenous welding.

While autogenous orbital welding has become routine in the biopharmaceutical and related industries, orbital welding with the addition of filler wire is generally unfamiliar. In-place welding in the field using manual GTA welding with the addition of filler wire is very unlikely to achieve a smooth inner weld bead. Smooth inner weld beads are necessary for the cleanability of high purity tubing systems which are used in these industries. Orbital GTA welding with the addition of wire is a viable option. This presentation will discuss the ASME BPE Standard, and the techniques, tube end preparation, equipment considerations and operator training requirements for orbital welding of corrosion resistant materials for the above mentioned industries.

1 Introduction: The ASME Bioprocessing Equipment (BPE) Standard

Most, if not all, new biotech and pharmaceutical installations in the United States and many in Europe use the American Society of Mechanical Engineers (ASME) Bioprocessing Equipment (BPE) Standard¹. The BPE Standard covers the design of equipment used in the bioprocessing, pharmaceutical and product care industries. The Standard also covers aspects which relate to sterility and cleanability such as plant piping. The piping area of the Standard includes guidance on: materials, dimensions and tolerances, surface finish, and material joining. The BPE Standard, was first published in 1997 as an American National Standard. With the 2002 Edition, the BPE Standard became an International Standard and it is now recognized in at least 30 countries. The current edition is the 2007 revision.

Materials of construction for the biotech and pharmaceutical industries must be resistant to corrosion from high purity water as well as buffer solutions used in the preparation of products and cleaning solutions used for CIP. Type 316L (UNS No. S31603) was initially specified by the BPE for bioprocessing equipment because it is sufficiently corrosion resistant for most bioprocess applications, the material was commercially available and it offers ease of fabrication. The 2007 Edition of the BPE Standard mentions that higher grade materials, such as the 6-Moly superaustenitic alloys (AL6-XN, UNS N08367, is the example listed), or 2205 duplex stainless steel (UNS S31803 or S32205) may also be used. The owner/user is responsible for the selection of appropriate materials of construction for the specific process.

It is not enough to specify the use of a corrosion resistant alloy, since without proper materials handling, fabrication techniques and welding procedures much of the corrosion resistance of the base material may be lost. Recognizing the need for a comprehensive approach, the BPE standard was one of the first standards to specify automatic or machine welding processes such as orbital welding as the preferred joining technology, and 316L stainless steel for tubing and weld components for hygienic tubing systems². In today's biopharmaceutical environment, where 20,000 to 30,000 welds may be required to complete a process piping installation, virtually 100% of the field welds on product contact surfaces are now done with orbital welding. Orbital welding, by definition is: "automatic or machine welding of tubes or pipe in-place with the electrode rotating (or orbiting) around the work". Orbital welding, as it applies to the biotech-pharmaceutical industry, uses the gas tungsten arc welding (GTAW) process in which the welds are usually done autogenously, that is, the ends of the tubing are fused together without the use of additional filler metal. However, the use of GTAW with the addition of wire is permitted and may be appropriate for some alloys or applications. Orbital welding offers the advantage that once acceptable welding procedures have been developed for a particular heat of

material, the power supply can reproduce identical weld parameters for every weld in the system. The BPE now requires the permission of the owner in order to make a manual weld on a joint to be done on a product contact surface.

2 Orbital GTAW equipment for autogenous and wire feed applications

Pharmaceutical tubing (ASTM A270 S2)³ is generally thin wall, i.e., 0.065 inch for diameters from 1 to 3 inches, and 0.083 inches for 4 inch diameter tubing. Orbital wire feed equipment is typically used for heavier wall on pipe diameters from 4 inch pipe and up. And, although orbital welding with wire has been used successfully on small diameter duplex stainless steel in the offshore industry, this technology is virtually unknown in the fabrication of pharmaceutical piping systems.

2.1 Orbital weld heads: Enclosed vs. open frame

The equipment used for orbital welding with the addition of wire differs in several important ways from that used for autogenous orbital welding (Fig. 1). The enclosed weld heads used for autogenous orbital welding provide a continuous shield with inert gas flowing for the entire weld joint during prepurge, the weld sequence, and postpurge which allows cooling of the weldment before exposing it to atmosphere.

With the orbital open frame heads used for adding wire the shield gas is limited to the electrode and the weld pool directly beneath the electrode. The resulting weld has considerably more heat tint discoloration on the OD surface than with



Fig. 1: Left: an orbital weld head used for autogenous welding. During welding the entire outside surface of the weld joint is protected by inert gas shielding. Right: an open-frame orbital weld head is shown welding a duplex stainless steel tube. Wire is being added to the weld. The gas cup provides shielding of the tungsten electrode and weld pool only. The welded surface is exposed to atmosphere before it has entirely cooled. *Photos courtesy of Arc Machines, Inc.*

an enclosed head. The ID purge is controlled independently for both autogenous and wire feed welding and achieving a clean color-free weld on the ID depends on the gas quality and the purge set up and techniques. With an enclosed head, however, it is possible to adjust the ID purge pressure to prevent ID convexity and achieve a flat inner weld bead surface which is ideal for biopharmaceutical applications. The pressure balancing technique does not work with an open frame weld head and some inner weld bead reinforcement occurs.

With an enclosed weld head the tubing and/or components are held in position using tube clamp inserts or collets for the exact tube diameter that are installed on both sides of the weld head. The electrode is lined up to the joint. Once the START button is pushed, the entire process is completely automatic. For an open frame head, the joint components must be tack welded in place or a bridge clamp used. A clamp on one side of the head holds the tube or pipe. The head must be properly aligned with respect to the weld joint and the wire angle and wire distance from the joint set. Orbital welding with wire feed is not fully automatic. Some adjustments such as torch steering to track the joint or adjustment to arc gap may be required. This takes considerably more operator skill than autogenous welding. While a welding operator can be trained for autogenous welding in two days, a minimum of four days is required to train an operator for wire feed orbital welding. Experience with manual welding is particularly helpful for wire feed operators who must be able to “read the puddle” in order to make parameter adjustments during welding.

Water cooling of the cables and weld heads is done to prevent damage to the weld head from excessive heat and thereby to improve productivity.

2.2 Orbital GTAW power supplies.

Power supplies are microprocessor based and control all of the weld parameters. The parameters for a particular diameter, wall thickness of tube or pipe are stored in memory as weld schedules. These schedules are reproduced and applied consistently for each weld joint. In addition to the welding current, travel speed, pulse times, level times or position used in autogenous welding, power supplies with wire feed capabilities have additional controls. As a minimum this would include wire feed speed and provisions to advance or retract the wire. In addition full function weld heads have controls for oscillation of the torch across the weld joint and electronic arc gap control (AVC) that maintains the correct distance between the electrode tip and the weld joint. The power supply must have the capability of controlling oscillation and AVC if these functions are required. The operator of orbital wire feed equipment views the progress of the weld so that he can make adjustments to the weld parameters in response to changes in the weld pool.

3 Type 316L Stainless Steel

Autogenous orbital welding of type 316L tubing and components in the size range from 1.000 inch (25.4 mm) to 4 inches (100 mm) with wall thicknesses of 0.065 to 0.083 inches (1.65 mm to 2.1 mm) has become highly systematized. It is not enough for the power supply to repeat identical instructions for each weld, but weld end chemistry, dimensions and installation procedures must also be consistent in order to achieve weld repeatability. Installers using the BPE Standard today can routinely achieve a very low weld reject rate and high productivity when compared to manual welding or even when compared to orbital welding installations done in the 1980's and early 1990's.

Prior to the publication of the BPE Standard in 1997, heat to heat variations in type 316L stainless steel and dimensional differences in wall thickness and ovality of fittings and weld components made it difficult to achieve consistency of weld results. On a typical installation in the 1980s, fittings and components from Korea, the US, Canada, Japan, etc. would have required individual weld schedules be developed for each type of component. By 1994, contractors performing high purity installations had developed procedures for improving weld repeatability. They initiated Standard Operating Procedures (SOPs) that were written instructions for their welding personnel so that cleaning, cutting, end-preparation, etc. were performed the same way each time by welding personnel. Kinetic Systems, Inc., a high-purity contractor tracked 100,000 orbital weld in 16 different bioprocess installations and were able to improve their orbital weld reject rate from 1.8% to 0.2% in the years from 1991 to 1994.

3.1 Visual Weld Criteria

The BPE Subcommittee for Design for Sterility and Cleanability offers guidelines for the design of process equipment to facilitate maintenance of a clean and sterile condition. The welds are considered to be part of the BPE standard's design concept for cleanability in that they must have full penetration of the weld joint to provide a crevice-free surface and a weld bead profile that is well-aligned and neither excessively concave nor convex. Conformance to these criteria promotes drainability and reduces the possibility of micro-organisms becoming established in the system. To qualify to the BPE, welds and welders must meet the requirements for ASME Section IX of the BPVC⁴ and ASME B31.3 Process Piping⁵, but must also meet the visual requirements of the BPE Materials Joining Part that are illustrated in figure MJ.1 (Fig. 2) and detailed in Table MJ-3.

Fig. MJ-1 Acceptable and Unacceptable Weld Profiles for Tube Welds

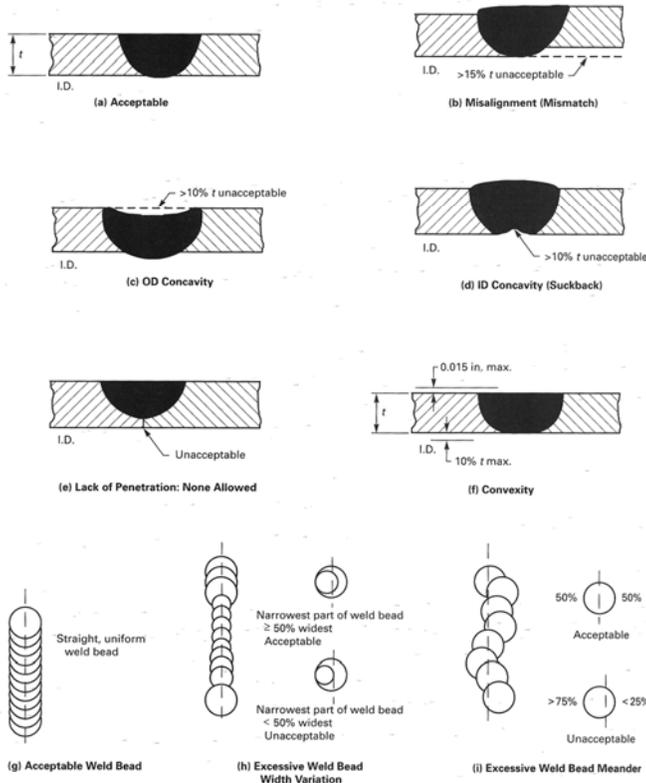


Fig. 2: Figure MJ 1. from the Materials Joining part of the ASME Bioprocessing Equipment (BPE) Standard. *Reprinted with permission of the ASME.*

3.2 Control of Weld End Dimensions

The expectation is that orbital welding will improve the consistency of weld quality compared to manual welds so that hundreds, or thousands of identical high-quality welds can be produced, but this does not happen automatically. The BPE Subcommittee for Dimensions and Tolerances (SCDT) has worked to achieve standardization of orbital welds by controlling the dimensions of weld ends of fittings and other process components such as valves. The joint configuration, normally a square butt end preparation, must be identical for each weld and the material chemistry must be similar in order to achieve a high degree of consistency from weld-to-weld. For example a tube wall thickness variation of 0.002 to 0.003 inches can result in a change of 2 or 3 amperes of welding current needed for penetration. If the end of the tube or fitting is not exactly perpendicular or the angle is offset, the weld ends will not line up correctly in the weld head and a welding defect is more likely (Fig.3). For tube end-preparation, installers typically use an orbital saw followed by a machine end prepping tool to assure a square end so the weld components fit together in the orbital weld head without a visible gap.

Table DT-5 Final Tolerances for Mechanically Polished Fittings and Process Components

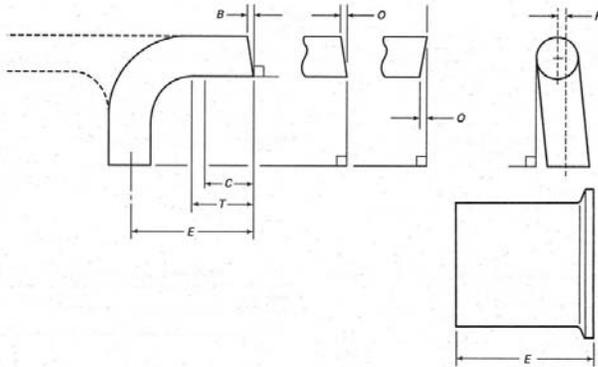


Fig. 3: The ASME BPE Subcommittee on Dimensions and Tolerances has defined limits for squareness and ovality of weld ends on tubing system components. *Reprinted with permission of the ASME.*

3.3 Control of Material Chemistry

The BPE SCDT has also sought to standardize the installation process by controlling the chemistry of 316L stainless steel which is the most frequently used material for high-purity bioprocess tubing systems. Heat-to-heat variation in the chemistry of stainless steel is well documented. Since trace elements have an effect on the melting characteristics of metals, each heat of stainless steel will vary somewhat from the next and this variability results in differences in weldability.

The element sulfur in particular produces dramatic differences in the weld pool shape and these changes occur in the concentration range specified for type 316 stainless steel⁶. If a tube with a sulfur concentration at the low end of the sulfur range, i.e. below 0.005 wt.%, is welded to a fitting at the upper end of the sulfur range for which the AISI (American Institute of Steel and Iron) specifies

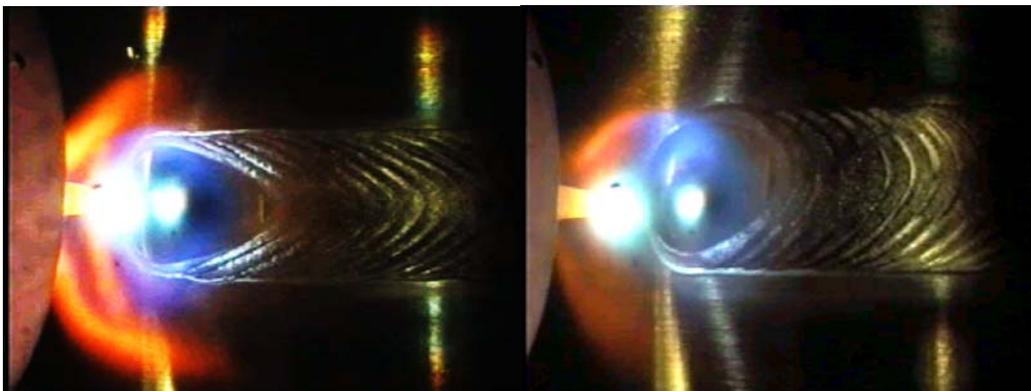


Fig. 4: Left: Symmetrical weld pool results from welding tubes with identical sulfur concentrations (0.008 wt.%). Right: Asymmetrical weld pool results from welding low sulfur (0.002 wt.% top) to higher sulfur heat (0.014 wt.%). The weld pool on the right is shifted towards the low sulfur heat. *Video clips from Arc Machines, Inc.*

a maximum value of 0.030 wt.%, the weld pool may shift towards the component with the lower sulfur concentration (Fig.4). This can result in an unpenetrated weld.

Before the BPE Standard was released in 1997, some installers spent hundreds of thousands of dollars on delays and problems related to mismatched sulfur concentrations. Segregation of material heats by sulfur concentration became an SOP for installing contractors before the BPE introduced a limited range for sulfur. Specifying both an upper and lower limit for sulfur for type 316L of 0.005 to 0.017 wt.% has streamlined the installation process and eliminated most problems related to weldability for those using tubing and fittings that conform to the BPE Standard.

Reducing the upper limit of sulfur has also improved corrosion resistance and surface finish by limiting the number of manganese sulfide inclusions found in materials at the higher end of the AISI specification. However, electropolishing and corrosion resistance would be further improved by selection of materials with sulfur concentrations within the lower end of the BPE range. (Fig. 5)

Table DT-3 Chemical Composition for Automatic Weld Ends, %

Material	%
Carbon, max.	0.035
Chromium	16.00–18.00
Manganese, max.	2.00
Molybdenum	2.00–3.00
Nickel	10.00–15.00
Phosphorus, max.	0.045
Silicon, max.	1.00
Sulfur	0.005–0.017

Fig. 5. Table DT-3 from the ASME BPE 2007 Standard showing the BPE material specification for Type 316L stainless steel weld ends. *Reprinted with permission of the ASME.*

3.4 Ferrite

While Type 316L base metal is austenitic, during welding it solidifies as delta ferrite and then transforms back to austenite leaving some residual ferrite in the weld metal. While the amount of ferrite may affect corrosion resistance, the BPE Standard has not addressed this issue. A BPE Task Group on Ferrite has been formed under the direction of the Metallic Materials of Construction Subcommittee in recognition that the European BN2 Norm, which has a very low requirement for ferrite, is being applied to orbital welds in Europe. Rather than specify a particular ferrite number, the BPE may simply list the amount of ferrite expected for welds on various product forms and chemical compositions of stainless steel in a future edition of the Standard.

3.5 Discoloration/Heat-tint

Proper inert gas purging to prevent the formation of “heat tint” during welding is critical to maintaining the corrosion resistance of type 316L stainless steel. The amount of color or heat tint produced during welding of stainless steel is proportional to the amount of oxygen and/or moisture in the purge gas and has a direct bearing on the corrosion resistance of the weldment. The BPE Standard specifies color-free welds on the product contact surface, while some slight bluish or gold color may be permitted in the heat-affected-zone of the weld. The BPE references the color chart in the American Welding Society (AWS) D18.1/D18.2 Specification for Welding of Austenitic Stainless Steel Tube and Pipe Systems⁷ (Fig. 6). Typically discoloration levels higher than sample number 3 have been unacceptable for bioprocess piping systems, but this level must be agreed upon by the owner, installing contractor and inspection contractor before the start of a piping system installation.

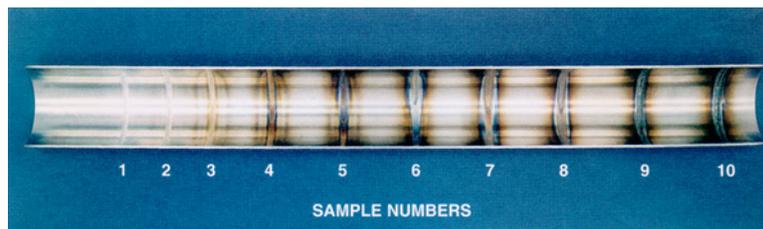


Fig. 6: Color chart from the AWS D18 Standard showing increasing amounts of discoloration (heat tint) with increasing amounts of oxygen in the ID purge on a series of orbital welds on a 316L stainless steel tube.

Corrosion, of course, is a source of contaminants and it is very difficult to maintain the cleanliness of a corroded surface. Whereas welds on fittings and other piping system components are usually mechanically polished or electro-polished before installation, welds in pharmaceutical piping systems are put into service in the “as welded” condition. The only post-weld treatment they receive is passivation with nitric or citric acid-based solutions. While passivation helps to restore the natural distribution of elements such as chromium and nickel in the outer surface layer and to remove free iron from the surface, it does not remove heat tint which can extend several hundred angstroms beneath the surface where it is not affected by passivation⁸. Thus achieving an adequate ID purge with minimal heat tint discoloration helps to retain the corrosion resistance of the material during welding.

Aside from cleaning and facing of weld ends, the BPE Standard does not recommend any welding techniques or practices to help meet the weld criteria of the standard. However, SEMI Standard F79-0304 Practice for Gas Tungsten Arc (GTA) Welding of Fluid Distribution Systems in Semiconductor Manufacturing

Applications⁹ recommends specific flow rates for inert gas purging and exit orifice dimensions for each pipe diameter. SEMI also recommends the use of a Magnehelic pressure gauge to determine the flow rate that will result in optimum purge pressure at the weld joint. Excessive pressure results in ID concavity or blowing out the weld, while too low pressure results in insufficient purging and weld discoloration. The gauge is connected by a tee at the weld joint, the flow rate adjusted and the tee is removed prior to welding. These purging techniques are also being used in the biopharmaceutical industry.

3.6 Weld QA/QC

On a biopharmaceutical tubing system installation using the BPE Standard there are provisions for examination and inspection of welds to assure that the finished welds meet the specified requirements. Radiography is not required, but all of the welds are examined on the outside and minimum of 20% of welds are inspected on the inside visually with a borescope. Sample welds, or test coupons, are made on a regular basis during construction to assure that the welding equipment is working properly and that the level of discoloration is acceptable (Fig. 7).

Extensive documentation is generated and handed over to the owner at the end of construction. Each weld in the system has a unique number that can be traced to an isometric drawing creating a weld map. Details such as weld ID number, welding operator, date, whether or not the weld was inspected are captured on a weld log. Each heat of tubing and component part are fully traceable back to the mill.

While some loss of corrosion resistance of the base metal can be expected from fabrication and welding, the use of the BPE Standard, repeatable, proven weld procedures, good jobsite practices and post-weld passivation help to assure that the installed system will meet the intended purpose. It is generally safe to say that if a weld on 316L stainless steel looks acceptable as welded and has been properly passivated it probably will have good corrosion resistance. If the service life for a particular application is not as expected, perhaps a more corrosion-resistant alloy would be a better choice.

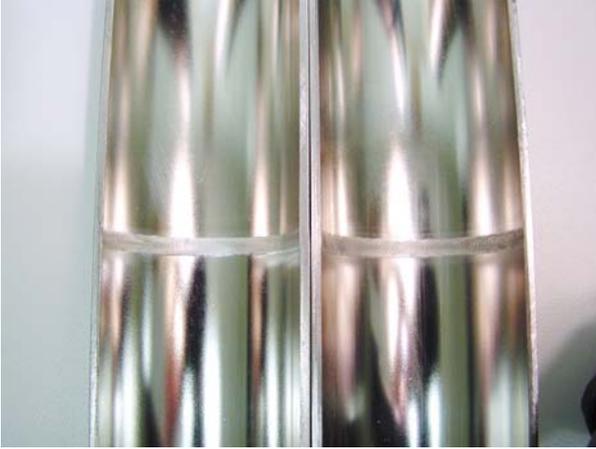


Fig. 7: Sample weld or weld coupon on an electropolished 316L tube cut open to view the ID surface. Such weld coupons are generated on a regular basis during construction of pharmaceutical piping systems. *Weld courtesy of Protech Process, Inc.*

4 Metallic Materials of Construction (MMOC)

The BPE has a subcommittee to address the use of metallic materials of construction other than 316L stainless steel. This subcommittee will establish weld criteria and surface finish requirement for nickel-based alloys as well as stainless steels that are more commonly used in Europe.

4.1 6-Mo Super-austenitic Alloys

It was recognized early in the development of the bioprocess industry, that for some bioprocess applications, a material with corrosion resistance superior to that of 316L would be required. The 6-molybdenum family of alloys was presented as a type of materials with the necessary degree of corrosion resistance, especially in the high-chloride environments seen in bioprocessing. These materials are super-austenitic and were developed for corrosion resistant applications in seawater where conventional stainless steels fail due to chloride pitting and crevice and stress corrosion cracking. However, it was noted that alloys high in molybdenum tend to lose a significant amount of corrosion resistance during welding unless filler material overalloyed in molybdenum is used during welding.

4.1.1 UNS N08367. In 1989, one of the 6-moly alloys, AL-6XN (UNS N08367), was selected for study to determine whether it could be successfully welded with equipment for autogenous orbital welding if an insert ring overalloyed in molybdenum was used to overcome the effects of molybdenum segregation¹⁰ (Fig.8). Autogenous orbital welds and orbital welds with C-22 insert rings tack welded in place prior to welding were compared to autogenous manual GTA welds and manual GTA welds with the addition of Inconel[®] 625 filler wire.



Fig. 8: AL-6XN tube samples with end preparation suitable for orbital welding. C-22 insert rings are tack welded in place prior to welding in an enclosed orbital weld head.

While fusion welds of both manual and orbital GTAW had significantly lower critical pitting temperatures (CPT) as determined by the ASTM G-48 accelerated corrosion test, the autogenous orbital weld had a higher CPT than the manual autogenous weld (Fig.9). The orbital welds with the C-22 insert rings had higher CPTs than the manual welds with filler. The orbital welds were subjected to bend and tensile testing to Section IX of the ASME BPVC and the insert ring technique with orbital welding has become widely accepted in the industry. The MMOC has determined that welds in ferrous alloys made with nickel alloy insert rings or filler metals must meet the acceptance criteria in Table MJ-3 of the BPE Standard with the exception that slag is permitted on the weld as long as it is silver to light gray in color and adherent to the surface.

Critical Pitting Temperature - Orbital and Manual Welds of AL-6XN

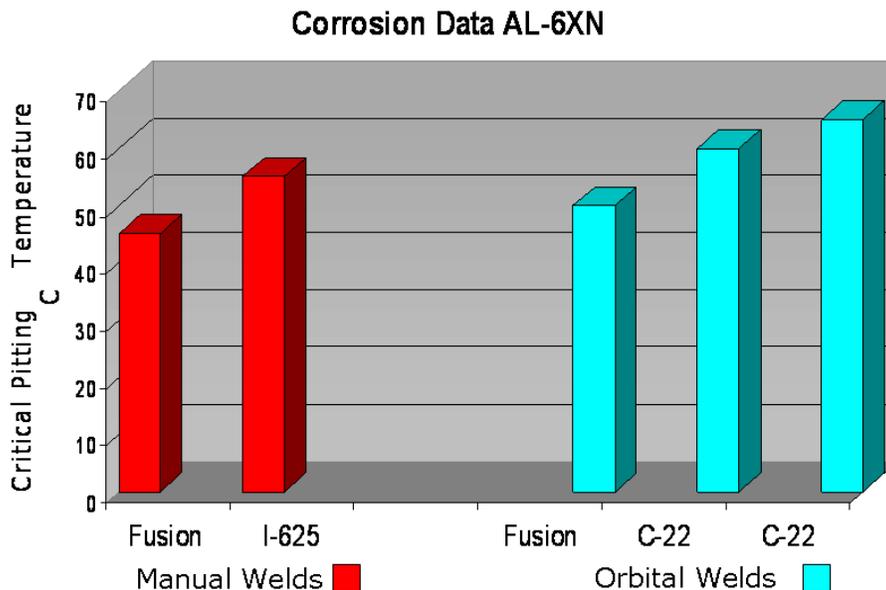


Fig. 9. Critical Pitting Temperatures (ASTM G-48) of welds of AL-6XN. Manual welds (left) were fusion or with the addition of Inconel 625 filler wire. Orbital welds (right) were fusion and with insert rings of Hastelloy C-22⁹.

4.2 Duplex Stainless Steel

Type 2205 (UNS S31803 or S32205) is a duplex stainless steel alloy with a combination of ferritic and austenitic microstructure. It has higher corrosion resistance than 316 (3% minimum molybdenum compared to 2% in 316), is highly resistant to stress corrosion and chloride cracking, but is not necessarily better than the super-austenitic (6% Mo) stainless steels in severe chloride stress corrosion cracking environments. Although 316L has been extensively used in biopharmaceutical piping applications, the use of duplex in this industry is only beginning. However, there is increasing interest in the material since it is corrosion resistant and, with the recent increase in the price of nickel, it is cost effective since it has only 5% nickel.

The challenge when welding duplex stainless steel is to achieve weld metal and heat-affected zones (HAZ) that have the same excellent corrosion resistance as the base material and the same toughness and mechanical properties. This depends on achieving welds with a balanced phase structure and preventing the formation of deleterious intermetallic phases such as sigma that may form during the welding thermal cycle in the temperature range of 1300-1800°F (705-980°C). Precipitates formed during welding can embrittle 2205 and lessen the ambient temperature ductility and toughness, and can reduce its corrosion resistance¹¹.

Duplex stainless steels are fully ferritic at welding temperatures and with the rapid thermal cycle during welding, there is a tendency for the ferrite component to increase at the expense of austenite. Nitrogen is added to duplex as an alloying element to promote the formation of austenite during solidification. Filler enriched in nickel compared to the base metal can also promote the formation of austenite. While using an insert ring enriched in nickel has been shown to be an acceptable method of adding filler to welds on duplex material¹², insert rings of the correct chemical composition are not commercially available. For autogenous welding, 2% nitrogen added to the shielding and backup gas has been found to counteract the loss of nitrogen from the weld pool.

4.2.1 Comparing autogenous orbital and orbital wire feed welding of thin wall 2205 duplex tubing

Welding procedures for duplex stainless steel should be designed to demonstrate the absence of deleterious phases and that the austenite/ferrite balance is within an acceptable range¹³. Although it has not yet been formalized, weld evaluation for BPE purposes would likely require two tests in addition to qualification to ASME Sect. IX of the BVPC which include bend tests for ductility and tensile testing. These would include ferrite counts of the weld and HAZ and corrosion testing to ASTM A923 Part C¹⁴.

In order to compare and evaluate both orbital autogenous and orbital wire feed techniques for suitability for service in biopharmaceutical piping (tubing) systems orbital welds, both autogenous and with the addition of wire, were made on 1.000 inch OD (25.4 mm) tubing with a wall thickness of 0.061 inches (1.55 mm). Argon gas with the addition of 2% nitrogen was used for both shield gas and ID purge for all of the welds. For the wire feed welds, the wire was 2209 which has 22% chrome and 9% nickel. All welds were done with a square butt end preparation in a single pass.

Five welds of each type were subjected to bend and tensile testing to ASME Sect. IX and welds were evaluated according to ASTM A923 Parts A and C.

Both autogenous and wire feed welds passed the bend and tensile tests demonstrating that no embrittlement had occurred. The samples were ground and polished using standard metallographic techniques in accordance with ASTM E3-01 procedures. The prepared sections were etched using 40% NaOH to reveal ferrite and austenite grain boundaries. Base material, weld, and HAZ located at the weld start and 180° were examined at 500X. The results for both autogenous and filler wire welds showed that the ferrite had been etched without revelation of intermetallic phase. The interphase boundaries were smooth.

The ferrite numbers were determined by point count from the micrographs of the weld and HAZ located at the weld start and 180°. Thirty randomly selected fields at each location were counted and averaged. For the autogenous welds the ferrite volume percent average of the HAZ counts was 63.8, while that of the welds averaged 67.4.

For the filler wire weld, the ferrite volume percent average of the HAZ counts was 62.3, while that of the weld metal was 57.

The results of the ASTM A923 Method C Corrosion Test done at 22° for 24 hours were as follows: the corrosion rate for the autogenous weld sample was 7.49 mdd, for the filler wire weld it was 5.81 mdd while the specification was for less than 10 mdd. No pitting was observed in either weld sample. These results suggest that either weld procedure is capable of producing welds with acceptable corrosion resistance on this material but that the addition of filler wire results in a more corrosion resistant weld. It should be realized however, that the corrosion rates of the base material with the longitudinal weld which is bright solution annealed after welding was only 0.4 mdd at 25°. It would be unrealistic to expect such good corrosion resistance of untreated welds.

While acceptable results were obtained on the ASTM A923 Method C corrosion test, this method does not take into account the actual surface that will be exposed to the corrosive environment in the biopharmaceutical process environment. In order to evaluate welds for the intended service one would like to test the corrosion resistance of the product contact surface after the post weld

passivation treatment. ASTM G-150¹⁵ can be used to evaluate the critical pitting temperature (CPT) on the ID surface of tubing. The edges are sealed off so that only the surface of interest is exposed to the test solution. But since this test is not widely available, it probably would not be included as part of acceptance criteria for welds intended for pharmaceutical piping systems. ASTM G-48 could also be used as a corrosion test that would evaluate the surface condition of the welds.

Interest in duplex stainless steel for use in the biopharmaceutical industry is increasing¹⁶. Our results suggest that orbital welding, whether autogenous, with insert rings or with the addition of wire can be used to make acceptable welds on a repeatable basis. What is lacking at this point is the availability of weld fittings and components in duplex materials for installation in hygienic pharmaceutical systems and equipment.

5 Conclusions

Welding of corrosion resistant materials inevitably results in some loss of corrosion resistance. A full solution anneal can reverse some or most of this loss. However, in pharmaceutical hygienic piping systems the welds are put into service in the “as welded” condition, the only post weld treatment being passivation. Orbital GTA welding is an excellent joining technology for corrosion resistant materials used in biopharmaceutical process piping. While autogenous orbital welding produces excellent results on Type 316L stainless steel, other alloys such as 6-Moly and duplex stainless steels may require or benefit from the addition of filler metal. This can be accomplished with insert rings in an enclosed type weld head for autogenous welding, or filler wire can be added using orbital wire feed equipment. Procedures must be developed for the alloy in question and appropriate prequalification weld tests performed.

For corrosion resistant alloys where the welding thermal cycle may be critical to the service performance of the alloy, orbital GTA welding with microprocessor-based power supplies can assure that the same weld parameters are applied on each similar weld joint. Thus proper joining and fabrication can assure that the corrosion resistant alloys installed in a hygienic system have retained as much of the base metal pre-fabrication corrosion resistance and mechanical properties as is practical.

6 References

1. ASME Bioprocessing Equipment (BPE) Standard 2007 American Society of Mechanical Engineers, Three Park Avenue, New York, New York 10016

2. Henon, B.K. Orbital welding in compliance with the new ASME Bioprocessing Equipment (BPE) 1997 Standard. *Pharmaceutical Engineering*, Vol. 19 No.1, January/February, 1999
3. ASTM A270 - 03a Standard Specification for Seamless and Welded Austenitic Stainless Steel Sanitary Tubing. ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959 United States
4. ASME Boiler and Pressure Vessel Code, Section IX: Welding and Brazing Qualifications 2007. American Society of Mechanical Engineers, Three Park Avenue, New York, New York 10016
5. ASME B31.3 - 2002 Process Piping. American Society of Mechanical Engineers, Three Park Avenue, New York, New York 10016
6. Henon, B.K., An Overview of the Effects of Sulfur on the Orbital GTA Welding of AISI Type 316L Stainless Steel Tubing and Pipe. Presented at the SEMI Workshop on Stainless Steel, Semicon Southwest, Austin, Texas, October, 2000
7. AWS D18.1/D18.2 Specification for welding of austenitic stainless steel tube and pipe in sanitary (hygienic) applications 1999 American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126
8. Grant, A., F. Mansfeld, and B.K. Henon. Effects of purge gas purity and chelant passivation on the corrosion resistance of orbitally welded 316L stainless steel tubing. Pharmaceutical Engineering: January/February and March/April, 1997
9. SEMI Standard F79-0304 Practice for Gas Tungsten Arc (GTA) Welding of Fluid Distribution Systems in Semiconductor Manufacturing Applications. SEMI Global Headquarters, 3081 Zanker Road San Jose, California 95134, U.S.A.
10. Henon, B.K. Orbital welding of corrosion-resistant materials for bioprocess piping applications. Presented at the ASME Bioprocess Engineering Symposium, San Francisco, California, 1989
11. Outokumpu Stainless. How to weld type 2205 Code Plus Two[®] Duplex Stainless Steel. Outokumpu Stainless, Inc. 425 North Martingale Road, Suite 1608, Schaumburg, IL 60173-3218 USA
12. Hayes, M.D. and B.K. Henon Approaches to the orbital welding of duplex stainless steel tubing of several alloy compositions. Presented at the Stainless Steel World America 2002 Conference, Houston, Texas, 2002
13. Outokumpu Stainless Corrosion Handbook Ninth Edition. Outokumpu Stainless Steel Oy, Riihitontuntie 7 A, P.O. Box 270, FIN-02201 Espoo, Finland

14. ASTM A923-06 Standard test methods for detecting detrimental intermetallic phase in duplex austenitic/ferritic stainless steels. ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959 United States

15. ASTM G150, Standard Test Method for Electrochemical Critical Pitting Temperature Testing of Stainless Steels. ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959 United States

16. AWS D10.18M/D10.18:2008 Guide for Welding Ferritic/Austenitic Duplex Stainless Steel Piping and Tubing American Welding Society, 550 N.W. LeJeune Road, Miami, FL 33126

7 Acknowledgements

The duplex stainless steel tubing 1.000" X 0.065" AVG S31803/S32205 was supplied by RathGibson, Inc., 2505 Foster Ave., Janesville, Wisconsin 53547-0389 USA

Welding wire, 2209 .023 diameter was supplied by High Quality Alloys, 12329 Telegraph Road, Santa Fe Springs, California 90670 USA

Testing of duplex stainless steel welds was done by Acute Technological Services, LLC 11925 Brittmoore Park Drive, Houston, TX 77041 USA

Robert Huddleston, Acute Technological Services, Carl Ketterman, RathGibson, Dr. Jim Fritz of TMR stainless and Bruce Green, Arc Machines, Inc. provided helpful discussion and interpretation of duplex stainless steel weld test results.

Frank Zych and David Just of Arc Machines, Inc. provided assistance with the wire feed welds on duplex stainless steel.