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Guidelines for welding and inspection of stainless alloy piping

Scope

This Technical Information Paper outlines considerations for fitup, welding and inspection of circumferential butt welds made during shop spooling and field installation of stainless alloy pipe and fittings; both thin wall (gauge) and thick wall (schedule). The stainless alloys included are austenitic stainless steels, duplex stainless steels, and nickel base alloys. It is assumed that:

- the weld root will not normally be accessible for direct visual inspection or repair
- all circumferential butt welds will be made using filler metal
- a solution heat treatment will not be performed after welding.

The goal is to provide guidance in obtaining welds appropriate for the intended service. The level of discussion is intended to provide background for evaluating or writing specifications. More detail about the subjects covered in this TIP is provided by the publications in the “References” section. References 1-3 provide useful general background.

Safety precautions

Adequate safety and industrial hygiene procedures must be in place for the cutting, welding, erection, cleaning, and inspection of stainless alloy pipe. The details of these procedures are beyond the scope of this TIP. In most cases jurisdictional or company policies will be in force. Anyone involved in welding or inspection of stainless alloy piping should make themselves familiar with the safety procedures in force on the job site.

Content

General considerations - codes and standards

ANSI/ASME B31.3 “Process Piping” (4) can be applied to pulp and paper industry stainless alloy piping. This code sets minimum requirements for materials, design, fabrication, and inspection of process pressure piping in a range of alloys and non metals. Other codes and standards (5, 6) may be useful in supplementing ANSI/ASME B31.3.

B31.3 is intended to cover process piping including steam and process chemicals, where pressure is greater than 103 kPa (15 psig) regardless of temperature. It may be mandatory in some jurisdictions or it may be referred to in specifications for stainless alloy piping. Simplistic specification statements like “fabrication and inspection shall

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conform to the ASME Code (ANSI/ASME B31.3)” should be avoided because confusion over specific requirements can arise. For example inspection requirements and acceptance criteria in B31.3 depend on the owner’s designation of the fluid service category involved (refer to the “Inspection” section of this TIP).

Alloy selection

The stainless alloy pipe, fittings, and weld filler should be selected to provide an adequate margin of safety against general and localized corrosion. Information on corrosion concerns and alloy selection is available in references 7-9.

Depending on the stainless alloy involved the corrosion resistance of a weld and the adjacent base metal can be reduced in relation to the unwelded base metal (10):

- the corrosion resistance of the weld filler metal may be reduced by microsegregation of molybdenum and other alloying elements during solidification of the filler (11).
- the corrosion resistance of stainless steel weld filler metal to inhibited hydrochloric acid cleaning solutions can be reduced by the formation of ferrite networks. The ferrite phase is corroded preferentially by hydrochloric acid (12, 13).
- the corrosion resistance of the heat affected zone in the base metal can be reduced by the precipitation of undesirable phases or, when welding the 6% molybdenum and similar highly alloyed austenitic stainless steels, by the formation of an unmixed zone where the base metal is melted but not mixed with the weld filler (1,14).
- the corrosion resistance of the base metal may be reduced by formation of surface oxide scale as a result of welding heat and inadequate protection of the weld root from oxidation (15-17).

Weld filler metal

To address weld metal microsegregation a more highly alloyed (overmatching) filler metal may be used for some services. Overmatching filler metal is most often required in acidic or near neutral pH oxidizing chloride environments in which the resistance to localized corrosion of the weld metal must at least match that of the wrought base metal. For example nickel-chromium-molybdenum (nickel based) filler is commonly used for welding 6% molybdenum austenitic stainless steels (11). Overmatching filler is generally not required in kraft liquor service or in paper machine white water service.

Where an overmatching filler metal is used it may be necessary to limit how much the filler metal is diluted by the base metal to be sure the intended overmatching is achieved. With butted joints or joints with narrow root gaps so little filler can be added that the goal of overmatching is not achieved. For the 6% molybdenum austenitic stainless steels it is important to ensure a sufficient root gap so that the weld metal will be well mixed with the base metal in the root bead. It is also possible to use consumable inserts for root welding (14).

The table below shows some commonly used stainless alloys and weld fillers with their American Welding Society (AWS) designations. The prefix E denotes stick electrode for shielded metal arc welding (SMAW) or flux cored electrode for flux cored arc welding (FCAW). The prefix ER denotes bare metal rod for gas metal arc welding (GMAW) or gas tungsten arc welding (GTAW).

Alloy	“Matching “ filler metal	Overmatching filler metal
304L austenitic stainless steel	AWS E or ER308L	not generally used
316L austenitic stainless steel	AWS E or ER316L	317L is sometimes used
316L with 2.5% Mo		317L
317L austenitic stainless steel	AWS E or ER 317L	904L is sometimes used
Alloy 20	AWS E or ER320	
904L	AWS E or ER385	AWS E or ERNiCrMo-3
6% molybdenum austenitic stainless steels	matching filler not generally recommended or available	AWS E or ERNiCrMo-3
high nitrogen, high molybdenum superaustenitic stainless steels	matching filler not generally recommended or available	appropriate fillers are available from alloy suppliers
2304 duplex stainless steel	matching fillers may be available from some alloy suppliers	AWS E or ER2209
2205 duplex stainless steel	AWS E or ER2209	appropriate fillers are available - consult alloy suppliers
2505 and 2507 type duplex stainless steels	AWS E or ER2553 or matching fillers available from alloy suppliers	AWS E or ERNiCrMo-3 or as recommended by alloy suppliers
nickel base alloys	consult alloy supplier for appropriate fillers	

Heat affected zone (HAZ)

The formation of phases or structures that can reduce the corrosion resistance of the base metal heat affected zone depends on alloy chemistry and welding procedure. For austenitic stainless steels and nickel base alloys heat input should be minimized. For duplex stainless steels the heat input should be controlled within an optimum range (18, 19).

Surface oxides

The negative effects of weld-related oxide scales and heat tint are best eliminated by preventing their formation through adequate inert gas purging of the weld root. Where oxide scales and heat tint form they can be removed by pickling with pastes or fluids containing nitric and hydrofluoric acids or by other surface cleaning methods including abrasive blasting and sanding. Acid pickling usually provides the best results but is seldom practical for field welds because of access, safety, and environmental considerations.

Requirements for prevention and/or removal of oxide scale and heat tint should be based on an assessment of the costs and benefits in a given application. For example heat tint is not a concern in alkaline liquor service.

Weld quality

Welds in stainless alloy piping should in general meet the quality requirements of ANSI/ASME B31.3. Special or supplementary requirements may be warranted for some service conditions depending on:

- corrosivity
- loading conditions - e.g. vibration, hammer, stock stick-slip phenomena, etc. ANSI/ASME B31.3 provides guidance on load considerations.
- special surface finish requirements - e.g. headbox approach piping

Accordingly it is difficult to generalize about acceptable levels of weld imperfections which may include:

- cracking
 - may grow easily by fatigue, not acceptable in ASME pressure piping codes
- incomplete root penetration
 - stress raiser for crack initiation

- site for fiber/deposit build up which could cause crevice corrosion or release in clumps causing process problems (e.g. headbox approach piping)
- lack of fusion (embedded)
 - stress raiser for crack initiation
- porosity, slag (if aligned may be interpreted as a linear defect by some codes)
 - if embedded are stress raisers
 - if exposed on the process side are stress raisers and possible sites for corrosion
- poor root profile (excessive reinforcement, steep merging angle to base metal)
 - stress raiser for crack initiation
 - site for fiber hang up
- irregular oxidized root
 - stress raiser for crack initiation
 - site for fiber/deposit build up
 - site for corrosion in some services

Figures 1 - 3 illustrate welds in thin wall stainless steel piping that were not fit for the intended purpose due to incomplete root penetration. The results were leaking due to corrosion and cracking due to fatigue.

Welding preparation

Avoiding iron contamination

All equipment for the storage, handling, and welding preparation of stainless alloys should be covered or faced with material that will prevent contamination by carbon steel particles. Grinding or sanding discs previously used on carbon steel should not be used on stainless alloys. Iron contamination can significantly reduce corrosion resistance in some alloy/environment cases while in other cases it is not a concern. For example carbon steel contamination (rust) of stainless alloys is not generally a concern for service in alkaline kraft liquors or on nonprocess side surfaces (except for appearance).

Cutting and grinding

Machining, sawing, grinding, or plasma cutting are commonly used to cut stainless alloy pipe. If plasma cutting is used care should be taken to protect the process side of the pipe from spatter. It is good practice to grind or sand plasma cut edges to remove the hard glassy residue from the cutting process.

Overheating during grinding should be avoided as it can reduce the corrosion resistance in some cases. Only grinding or sanding discs designed for use with stainless alloys should be used. Grinding or sanding discs previously used on carbon steel should not be used on stainless alloys.

Cleaning

The weld joint area should be free of burrs, lubricants, grease, paint, filings, and cuttings. Solvent cleaning should be done with non chlorinated solvents. Tools or materials used to clean joints should not contaminate the stainless alloy with iron, carbon or other residues. For example wire brushes or steel wool used to clean joints should be made from austenitic stainless steel which is nonmagnetic and be marked as stainless steel.

Joint Preparation

Joint preparation can influence penetration and weld metal dilution by base metal. An inadequate root gap may result in incomplete penetration and incomplete mixing of the filler metal with the base metal.

The joint preparation and root gap must be included in the welding procedure specification (WPS).