TIP 0402-29

ISSUED - 2001

Qualification of welding procedures for duplex stainless steels

Scope

This TIP reviews the current state of knowledge regarding duplex stainless steels, particularly as it affects their use in the pulp and paper industry. It addresses the definition of testing for qualification of weld procedures that are both technically and economically effective. The discussion focuses on 2205 duplex stainless steel and on digesters. However, the information will be generally applicable with appropriate modification for other duplex stainless steels and to other vessels and processors built of duplex stainless steels within the pulp and paper industry.

Safety precautions

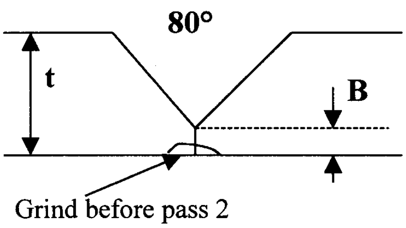
Any welding process requires appropriate safety precautions, techniques, and safety equipment (helmet, shields, gloves, etc.). Normal manufacturing safety precautions apply. Some companies require welding permits. Check with the appropriate department at your organization.

This TIP may require the use, disposal, or both of chemicals that may present serious hazards to humans. Procedures for the handling of such substances are set forth on Material Safety Data Sheets that must be developed by all manufacturers and importers of potentially hazardous chemicals and maintained by all distributors of potentially hazardous chemicals. Prior to the use of this technical information paper, the user should determine whether any of the chemicals to be used or disposed of are potentially hazardous and, if so, should follow strictly the procedures specified by both the manufacturer, as well as local, state, and federal authorities for safe use and disposal of these chemicals.

General guidelines for welding duplex stainless steels

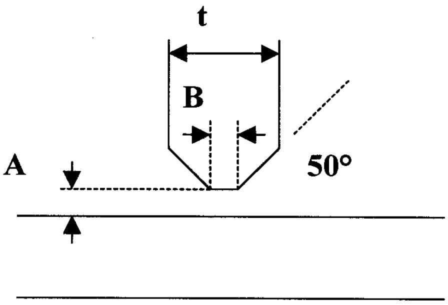
It is assumed that the reader already has experience in welding of austenitic stainless steels such as Type 316L in pulp and paper mill applications. This section addresses some to commonly discussed welding characteristics and procedures of the duplex stainless steels in terms of how they differ from austenitic stainless steels. Addressing each of these features is essential for the design of technically and economically effective welding procedures to be qualified.

The 2205 duplex stainless steel is far and away the most readily available grade with multiple producers of virtually all product forms and good availability through common metal distribution channels. The issues regarding welding of duplex stainless steels are similar for most grades so that a thorough discussion of 2205 is a sound basis for minor modification to accommodate the other duplex grades, whether of greater or lesser alloy content.



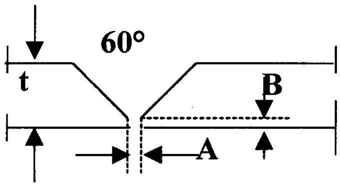
9 mm (0.36 in) < t < 12 mm (0.5 in)
B = 5 mm (0.2 in)

E. Suitable for SAW. Grinding after first pass facilitates full penetration.



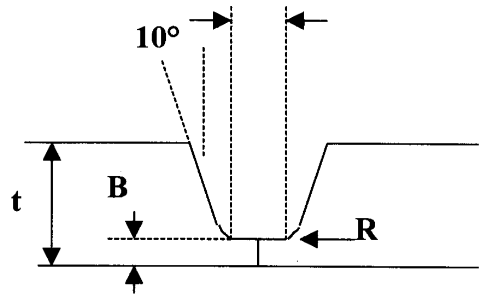
4 mm (0.16 in) < t < 12 mm (0.5 in)
A = 2.5 mm (0.1 in)
B = 5 mm (0.2 in)

F. Full penetration Fillet. Suitable for SMAW. Tack weld with SMAW or GMAW.



4 mm (0.16 in) ≤ t < 12 mm (0.5 in)
A = 2.5 mm (0.1 in)
B = 2.5 mm (0.1 in)

G. Single V Joint. Pipe welding. Suitable with SMAW.



3 mm (0.12 in) ≤ t < 12 mm (0.5 in)
B = 2 mm (0.08 in)

H. Single U Joint. Pipe Welding. Suitable with GTAW.

Preheating may be beneficial when used to eliminate moisture from the steel as may occur in cold ambient conditions or from overnight condensation. When preheating to remove moisture, the steel should be heated to about 95° C (200° F) uniformly and only after the weld preparation has been cleaned.

Preheating may also be beneficial in those exceptional cases where there is a risk for forming a highly ferritic HAZ because of very rapid quenching. Examples include welding a thin sheet to a plate, as with a liner to a vessel or a tube to a tubesheet, or any very low heat input weld where there is exceedingly rapid cooling. (See FAQ 13.) In such cases the heavier member should be heated to a temperature not to exceed the typical maximum interpass temperature of 150° C (300° F).

complete Methods B and C. The user may require reporting of actual test results for Methods B and C as a way of removing the permission to use Method A for screening. As noted below, the impact tests for the ASME requirements may be done at the more stringent condition of A 923 in order to save on testing costs.

The ASME toughness testing addresses the suitability for use of a particular construction, and the requirements depend on section thickness and minimum design metal temperature.[3] The ASME specification for duplex stainless steels, when applicable to a particular construction, require the more common set of three specimens for the Charpy test, and use lateral expansion rather than energy absorption as the acceptance criterion. The impact test requirements of the ASME specification are less stringent than those of A 923, unless the minimum design metal temperature is below –40° C (-40° F). It is possible that the ASME required testing would not detect the early stages of formation of intermetallic phases. But as noted in ASTM A 240, performing the ASME tests at the more stringent test temperature of A 923, with measurements of both impact energy and lateral expansion, is permitted and allows for cost saving by avoiding redundant testing. (See FAQ 15, 16).

Hardness tests of the starting material are of little value with respect to the determination that heat treatment has retained toughness and corrosion resistance through the elimination of intermetallic phases, but fortunately hardness tests are also of little cost. If hardness testing is required, as is the case for most duplex grades in the ASTM specifications, the maximum should be that listed in the specifications.

Sampling. It is important to qualify both the heat-affected zone and the weld metal itself for a duplex stainless steel. However, the testing procedure and acceptance criteria are likely to differ for the HAZ and the weld. In the case of austenitic stainless steels, there are seldom problems associated with the heat-affected zone, other that the possibility of sensitization, relatively unusual for the low carbon versions of these grades.

There are several situations in which it is necessary to qualify the welding procedure for a duplex stainless steel at different positions in the weld with regard to the thickness. For example, for a welding procedure calling for a GTA root pass followed by filling with another weld method, it is appropriate to test the weld both in the area of the root and at one or more levels within the filler passes. In multi-pass welds, each subsequent pass can have significant effects on the condition of the prior passes, such as altering phase balance, causing formation of secondary austenite, or causing precipitation of non-metallic or intermetallic phases.

Acceptance criteria. The appropriate acceptance criteria for welds, applicable to as-welded fabrications, vary widely from those applicable to annealed mill products, especially with regard to toughness measurements for flux-shielded welds. (See FAQ 9, 15, 16.)

Guidelines for testing for procedure qualification

For the qualification of the welding procedure, it is recommended that the following tests be performed for each significant geometry and thickness. Some judgment must be applied with regard to the differences in the proposed procedures with respect to total time at temperature and the rate of quenching that will be seen for the last pass of welding. For example, it is convenient but possibly unrealistic to weld plates in the flat, downhand position to qualify a procedure if it is known that the actual welds will be made with less than perfect fit-up or with substantially out-of-position welding.

It is common for a skilled welder to overcome minor deviations in fit-up with welding technique and local rework, and these may lead to extended time at temperature for the HAZ. Accordingly, it is prudent to qualify procedures for reasonably anticipated repairs or rework of welds. For example, when welds are to be radiographed, it is obviously the intention that any defects found will be repaired. Therefore, it is appropriate and economical to qualify a repair procedure for one or two successive repairs to be performed on piece that has been welded by the qualified fabrication welding procedure. Qualification of the major repairs should use the same tests as the qualification of the procedure for the fabrication weld. For minor repairs, it may be sufficient to perform only limited confirmation tests, such as the tests of ASME UHA-51 or ASTM A 923 Method C.

For the welding procedure qualification, the following materials and tests are typically specified:

Starting material (mill products)

1. Material should meet the appropriate ASTM product form specification (or ASME specification, as noted below, for Code-qualified construction). For 2205, the S32205 should be specified. For other duplex stainless steels it is recommended that the listed composition be accepted, but with consideration for further limits on composition. For those grades with nitrogen content range (max-min) in excess of 0.10%, chromium content

Hardness requirements

Because many of the early applications of duplex stainless steel were in the oil and gas industry and because this industry is accustomed to dealing with steels and stainless steels that are capable of martensitic transformation, many of the earlier specifications for duplex stainless steels required material not to exceed a hardness maximum. This hardness maximum is correct for controlling martensite, but not for controlling duplex stainless steel. The user would like to encourage the presence of nitrogen, but nitrogen increases both the yield stress and the rate of work hardening. Consequently, any maximum hardness requirement works against obtaining the optimal duplex stainless steel chemistry.

When hardness is specified, it is also important to specify where hardness shall be measured. Because the end user requires flat or straight products, the steel producer applies mechanical straightening, for example, by rolling, flexing, pressing, or stretching. The surface of the steel is hardened. It is most economical to measure the hardness at the surface. If the hardness exceeds a specified maximum, one should have the option of measuring below the surface, e.g., at quarter-thickness in flat-rolled products or half-radius in round bar or forgings, with the option to meet that same hardness limit on the surface. This is a conservative approach because one should expect that the surface will not be softer than the middle of the material.

Mircohardness measurements have been shown to be capable of detecting 475°C (885°F) embrittlement in the ferrite phase of duplex stainless steels. However, a microhardness measurement samples only a very small volume of material and can easily miss a detrimental condition such as intermetallic phase precipitation. Even hardness measurements which sample a larger volume of material, such as Rockwell B and C, are not an appropriate test to unambiguously detect the formation of intermetallic phases because high hardness values may also be a result of thermomechanical processing. A metallographic examination of the cross section of a piece of steel can reveal far more about its condition than any hardness measurement.

Impact toughness requirements

Duplex stainless steels are exceedingly tough materials. Mill plates typically have impact toughness levels that approach or exceed 225 J (165 ft.-lb.) for longitudinal samples (long axis parallel to the rolling direction, notch axis perpendicular to the rolling face) tested at -40°C (-40°F). The ductile-to-brittle transition is not sharp as it is in a ferritic stainless steel, but rather exhibits a moderate slope from the upper shelf energy to about 50 to 75 J (35 to 55 ft.-lb.) at about -100°C (-150°F). The presence of the austenite in the duplex structure, when that phase is unaffected by intermetallics, assures some toughness even down to low temperatures. The toughness of wrought duplex stainless steels is strongly anisotropic. Because the product is rolled in the duplex temperature range, the duplex structure is elongated. For plate, depending on the extent of cross rolling, the transverse Charpy sample (long axis transverse to the rolling direction, notch axis perpendicular to the rolling face) exhibits one half to two thirds of the shelf energy of the longitudinal sample. Although not widely documented, it is estimated that the through-thickness Charpy specimen (long axis perpendicular to the rolling face) has a shelf energy that is about half of that of the transverse specimens. But even in this least tough direction, the impact energy is still higher that the toughness that has been considered acceptable for large pressure-containing fabrications in carbon steel.

Toughness tests for intermetallic phases (ASTM A 923, Method B). ASTM A 923 Method B uses the Charpy test as an acceptance procedure for duplex stainless steel mill products to demonstrate the absence of detrimental intermetallic phases. It uses a single specimen rather than the set of three for the typical Charpy test because the A 923 test uses the absence of embrittlement as an indicator of the absence of the embrittling intermetallic phases. At present, only S31803 and S32205 have an acceptance criterion. The acceptance criterion is 54 J (40 ft.-lb.) for a full-size Charpy, longitudinal impact specimen, tested at -40°C (-40°F) with a linear, proportional reduction of the required minimum impact energy for subsize specimens. A 923 permits any specimen orientation provided that the energy achieved is equal to that required for the longitudinal specimen, known to be the toughest orientation. Testing transverse specimens is often economical for the cutting of specimens with minimal loss of useful material, and it is conservative if the same acceptance criterion is met.

The acceptance criterion of 54 J (40 ft.-lb.) at -40°C (-40°F) is high relative to toughness requirements in common fabrications, but it is appropriately conservative for detection of intermetallics in an annealed mill product. This test was not intended to qualify toughness for welded fabrications. As stated in the specification, A 923 was written for the qualification of mill products and may not be directly applicable to weld qualifications or to weld fabrications. ASTM A 923 addresses, with a few exceptions, the occurrence of intermetallic phases in annealed mill products.

for a specific application. These tests detect the formation of intermetallic phases to the extent that an important engineering property, corrosion resistance, may have been compromised. The relationship of ferric chloride testing to any service environment must be established independently.

The formation of intermetallic phases on the order of 1 vol. pct. will cause a significant lost of corrosion resistance. It is useful to think of precipitation of intermetallic phases in terms of a sensitization, not to intergranular corrosion but rather to pitting attack not limited to the grain boundaries. The low diffusion rates of the elements in intermetallic phases are responsible for the pervasive nature of the precipitation. The effect may be as large as a loss of 20°C or more in the critical pitting temperature. Even when the toughness of the steel is not of particular concern in an application at somewhat elevated temperatures, the loss of corrosion resistance may be a concern because that is usually the fundamental basis for selection.

Corrosion testing has the advantage of being almost insensitive to specimen location or orientation. If an intermetallic phase is exposed anywhere on a ground surface, a ferric chloride test will find it.

ASTM A 923, Method C. It has been customary to specify corrosion testing in terms of a "modified ASTM G 48 test", but seldom has the modification been adequately detailed. G 48 is a laboratory tool, not an acceptance test. It does not define a test temperature, test duration, or sample size and orientation. It does not produce a numerical result, and its method of determining the presence or absence of pitting, needle scratching the surface under magnification, is open to interpretation and controversy. ASTM A 923 Method B uses the same equipment as G 48, but does not reference G 48. It defines for 2205 (S31803) that the test shall be at 25°C for 24 hours on a sample with uniform surface at least equal to a 120-grit finish, or finer. Corrosion is measured by a weight loss that is converted to a corrosion rate, so a standard specimen size is not necessity. The weight loss required is large enough to be convenient to measure, but small enough to be associated with development of a single pit in 24 hours. While G 48 allows ignoring corrosion on the edges of the sample, A 923 allows no such exception because it evaluates for the presence of detrimental intermetallic phases, and these phases rarely emerge from the major faces of the steel. Any acceptance of edge attack is a dangerous and non-conservative in duplex stainless steels testing.

The corrosion test has the advantage of being relatively rapid, requiring 24 hours plus sample preparation time. It is not sensitive to size or orientation, provided that edge attack is not ignored. It is reproducible, with little chance of a false indication for material without some detrimental phase and virtually certain of attack when a detrimental phase is present.

Welded mill products. For mill products with a weld, such as pipe or fittings, it is necessary to reduce the test temperature even when the product is annealed, and especially when the product is annealed in-line so that time at temperature is short. While in-line annealing may eliminate detrimental phases, it is not long enough to assure homogenization of the segregation that can occur in the solidification of an autogenous weld. Accordingly, A 923 set a test temperature of 22°C for S31803for welded mill products. At the time A 923 was written, all duplex mill products were annealed. However, with the 1994 introduction of ASTM A 928 for duplex stainless steel pipe welded with filler, it is possible to specify a condition, designated "HT-O", where the product has not been annealed. Recent reports indicate that unannealed, welded 2205 has difficulty passing a 22°C test. It is likely that A 923 will be changed to include unannealed products as a matter for agreement between seller and purchaser on a case by case basis.

It is important to recognize that A 923 or "modified G 48" was never intended as a "fitness-for-service test" for a specific application. It detects the formation of intermetallic phases to the extent that an important engineering property, corrosion resistance, may have been compromised. The relationship of ferric chloride testing to any service environment must be established independently.

6. Can heat input be allowed below the mentioned bottom value of 0.5 kJ/mm as long as the ferrite content does not exceed 70% (for example, due to the over-alloying of the base and electrodes)?

Exceedingly low heat input is permitted, provided that the result is demonstrated to meet the usual requirements for phase balance and corrosion resistance.

7. Does soda lime glass bead blasting provide an adequate finish for corrosive service, as an alternative to pickling and what is the recommended surface profile range?

Whether or not a glass blasting will be sufficient for corrosive service will depend on the degree and nature of the oxidized surface and the corrosivity of the service, including the tendency of the medium to adhere to the surface of the steel. While a pickled surface provides corrosion resistance to the maximum capability of the grade, a thoroughly blasted surface may be sufficient and economical. Scale and heat tint for the duplex stainless steels are especially adherent and resistant to both mechanical and chemical removal.

8. What is the best way to prepare weld/HAZ specimens for A 923 Method C testing?

The specimen should be removed by the method least disruptive of the metal condition. Cold cutting is recommended if possible. If a hot cutting method is applied, then there should be further cold cutting or grinding to remove all material that was affected by the hot cutting. The surfaces tested should all be as ground without pickling or other chemical treatment that might clear the surface of detrimental phases. A slight chamfering of the edges is helpful, but the should not be substantial rounding off of the edges. The presence of burrs on the edges will cause weight losses not related to the presence of intermetallic phases. Corrosion attack on the edges must be included in the limiting acceptance criterion. "Modified G 48" procedures that permit disregarding of edge corrosion are not correctly testing for the presence of detrimental intermetallic phases.

9. Is "modified G 48" testing the same thing as A 923 Method C?

ASTM G 48 Practice A and A 923 Method C are similar to the extent that they use similar equipment and laboratory procedures. However, they are substantially different in their application. ASTM G 48 is a description of laboratory procedure, but it does not specify the temperature of testing, the time of exposure, the technique of assessing corrosion, and an acceptance criterion. The "modified G 48" test indicated that the individual ordering specification was attempting to address these deficiencies, but few specification addressed all of them. ASTM A 923 Method C specifically addresses each of these issues, and provides a basis for acceptance of the duplex stainless steels with regard to the absence of detrimental intermetallic phases.

One important difference is that G 48 permits the tester to disregard corrosion on the edges of the specimen. This permission is totally inappropriate for use of the test to demonstrate the absence of intermetallic phases in duplex stainless steels. It is unlikely that the intermetallic phases will occur in the faces of the plate or the faces of the weld, but rather will occur in the interior of the metal. Therefore, incidents of pitting on the edges of the sample should be considered indicative of a problem, and not ignored.

G 48 is usually a procedure performed at a series of temperatures, with the goal of identifying the critical pitting temperature. Accordingly, the time of exposure and the inspection for pitting on the surface are designed to detect subtle pitting initiation. The single test temperature for each grade in A 923 is chosen to be below the critical pitting temperature for material without intermetallic phases, and above the critical pitting temperature for material with intermetallic phases. The pitting, when it does occur, is readily visible. However, the weight loss is what is measured in order to remove the potential for debate over visual interpretation. That weight loss is converted to a corrosion rate in order to permit different sizes and geometries of specimens to respond to a single acceptance criterion.

An important issue is the surface preparation of the sample. The goal of the test is to detect intermetallic phases if present. Chemical treatment of the specimen surface (passivation or pickling) may reduce the exposure of intermetallic phases in the surface and thereby cause the test not to detect the presence of intermetallic phases. The specimen edges should be fine ground but not chemically treated for most effective use of the A 923 test. If there is concern that the faces of the specimen may contribute to the weight loss, the appropriate specimen preparation is to pickle the specimen before final grinding of the edges.