Corrosion Testing of Duplex and Superduplex Weld Metal

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Abstract. At the first Beaune duplex conference in 1991 a paper was presented by Metrode [1] that looked at the factors affecting weld root run corrosion performance in duplex and superduplex pipework. The current paper, for the 2010 conference, aims to provide an update and look at the current position regarding corrosion testing of duplex and superduplex stainless steel welds.

The use of duplex and superduplex stainless steels has continued to increase since 1991 but despite the knowledge and experience that has been acquired in welding these alloys over that time there are still problems encountered in passing corrosion tests. The increasing use of lean duplex stainless steels has also altered the perception of corrosion performance for duplex alloys and this aspect of corrosion testing will also be introduced because different corrosion tests and corrosion performance apply to lean duplex stainless steels.

Weld procedure factors will be revisited to see what additional knowledge has been gained since 1991 and how these factors affect corrosion performance. This will include looking at: weld composition, segregation, reheating (heat input balance), oxidation, nitrogen content, shielding and purging gas, and the practical constraints of the welding process.

Project and code requirements have become far more onerous, often without technical justification, so realistic test criteria will be presented. The standard corrosion test, ASTM G48, will be examined in detail looking at how the test is carried out and what the test is capable of determining. The controls necessary to achieve consistent test results will also be discussed; this will include the limitations of the process described in the ASTM standard and how the consistency of the test can be improved.

Examples of weld procedure corrosion testing failures will be presented and the reasons for failures will be investigated. The effects of weld procedure, testing procedure, weld consumables and potentially unrealistic code requirements will all be discussed.

1 Introduction

In the majority of instances, duplex/superduplex stainless steel butt joints enter service in the as-welded condition. Component size often dictates a single-side welding approach, with no opportunity to carry out any post-weld remedial operations on the weld underside which, in service, is the surface directly in contact with the process media. Consequently, a high degree of importance is attached to ensuring that production weld joints enter service with an appropriate and reliable level of as-welded fitness-for-service.

These requirements apply to the welding of all of the range of duplex stainless steels in the market today, Table 1, particularly where there is a priority for pitting resistance under exposure to aqueous Cl^- bearing media.

Table 1 2010 Family of Duplex Stainless Steel Grades

Grade	UNS	Cr	Ni	Mo	N	Cu	W	PREN	CPT, °C
Lean duplex	S32304	23	4	0.1	0.1	--	--	25	18
	S32101	21	1.4	0.1	0.2	--	--	25	20
Duplex	S31803	22	5	2.8	0.14	--	--	34	30
	S32205	23	5	3.2	0.18	--	--	35	33
Superduplex	S32750	25	7	3.8	0.24	--	--	41	70
	S32760	25	7	3.8	0.23	0.7	0.7	40	70
	S32550	26	7	3.5	0.25	1.8	--	41	70
	S39374	25	7	3.0	0.26	0.3	2.0	42	70
Hyperduplex	S32707	27	6.5	5	0.4	--	--	49	97

PRE_N = Pitting Resistance Equivalent : %Cr + 3.3 x %Mo + 16 x %N
(Note ; PRE_W is a recognised secondary calculation that includes the role of Tungsten,
ie. %Cr + 3.3 x (%Mo + 0.5 x %W) + 16 x %N

CPT = Critical Pitting Temperature, according to **ASTM – G48 Method E**, uses a ferric chloride solution to establish the temperature at which pitting attack on the surface of duplex stainless steels, to a depth of 0.025mm (0.001in or 1mil) minimum, can be detected.

Note : **ASTM – G48 Method A** relates to a similar ferric chloride pitting test, which is applied to duplex stainless steels, at specified temperatures (usually lower than the CPT), to assess material quality on the basis of exhibiting freedom from pitting, or meeting a maximum specimen weight loss. From industrial experience with welding of duplex stainless steels, two areas of major importance to confidence in weld quality can be identified:

1.1 Welding practice

Disciplined welding procedural practice is at the core of the ability to produce welded joints routinely capable of meeting specified design requirements. The basis of confidence is established at the welding and testing stage, ie. Weld Procedure Qualification.

The accent is predominantly on welding of the joint root, where heat input and cooling rate conditions are essential controls in ensuring a weld deposit and HAZ under-surface microstructure capable of requisite pitting corrosion resistance, over the full 360° of weld circumference.

1.2 Assessment of weld joint resistance to pitting attack

Many clients' fabrication specifications call-up the ASTM-G48 Method A test, at the Weld Procedure Qualification stage, to establish that appropriate fitness-for-purpose weld quality can be delivered. However, it is an established fact that the 'G48A' test, intended for testing parent materials, needs refinements for it to be applied effectively to the testing of welds, and these will be outlined.

2 Duplex stainless steel welding practice

A typical duplex stainless steel butt joint is, in essence, a *"weld of two halves"* as illustrated in Figure 1.

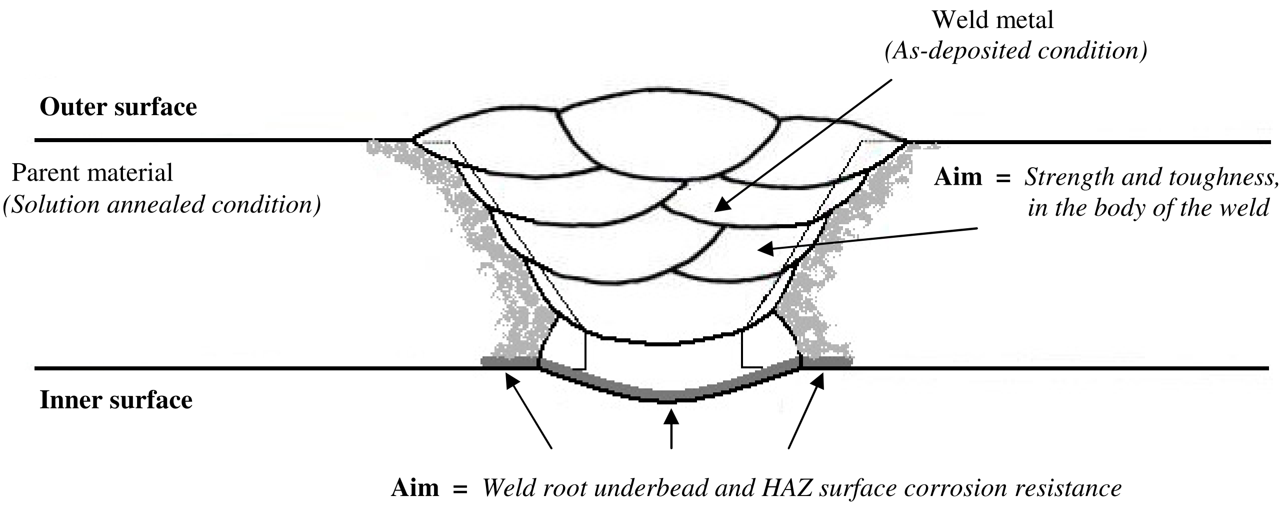


Figure 1: A weld of two halves: strength and toughness in the weld body and corrosion resistance in the root.

2.1 Joint root welding faces the challenge of depositing a sealing run with requisite fusion, soundness and uniform underbead profile. Heat input / controlled cooling rate requirements apply to deposition of both the root and 2nd 'cold pass' weld layers .

2.3 Joint completion, using welding practice similar to that with fabrication of standard austenitic stainless steel, eg. 304L & 316L, whilst avoiding excessive heat input, to ensure a joint with requisite strength and fracture toughness.

3 Root pass welding

Welding the open root configuration of single-side butt joints, particularly with smaller size components and in fixed positions places challenging demands on weld procedural control. The TIG/GTAW process' arc stability, weld pool control, positional operability, independent control of filler wire addition, and overall deposit quality makes it the first choice for manual deposition of initial pass(es) with the majority of single-side butt joints, especially those involving pipework sub-assemblies. With larger components and vessels involving both single and double-side joints, the productivity benefits offered by mechanised welding processes can be realised, eg. orbital and Mechanised GTAW, Mechanised GMAW (STT) or FCAW. In all situations, a number of key procedural disciplines apply and these are discussed in sections 3.1 to 3.9.

3.1 Contamination-free workshop practice

- Segregated stainless steel fabricating facilities. If necessary, a shop within a shop,
- protective roofing to avoid airborne contaminant fall-out,
- draught-free environment to protect gas shielding,
- stainless or non-metallic surfaced handling & storing facilities.

3.2 Joint preparation

- Plasma-cut + grind dressing, or mechanical sawing preparation,
- cutting & grinding tools dedicated solely for duplex stainless steel fabrication,
- 12mm wide internal and external band either side of the joint should be surface ground and solvent clean (Cl^- free).

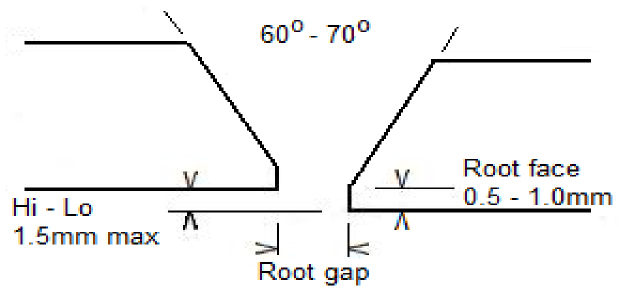
Contamination affects weld pool fluidity, root underbead surface finish & profile.

3.3 Joint configuration

- **Avoid**: → **to prevent**:

Narrow V-groove angles → Excessive joint root melting,
Thick root faces → Excessive parent material dilution effects,
Wide root gaps → Slower travel speed, higher heat input welding.

- Ensure rigid fit-up using 'bridge tacks' or welded-on duplex stainless steel 'bullet' spacers,
- Avoid tack-welding directly into the root gap,
- Avoid joint-restraining, welded - on 'cross bars',
- Typical joint configuration:



Wall thickness, mm	Root gap, mm
2 – 4	2 – 3
4 – 10	3 – 4
10+	4 – 5

3.4 TIG/GTAW gas shielding & back-purging

Torch

- Pure argon recommended; 10 - 15 lpm (20 - 30cfh).
- Argon + 2½%N_2 gasmix ǂ recommended for specifically demanding pitting corrosion test requirements, eg. superduplex stainless steel tested at 40^{0}C. Argon/nitrogen to be replaced by pure argon following deposition of the initial two root layers because excessive usage of argon/nitrogen shielding gas may lead to micro-porosity defects in the body of the weld.

Back-purge

- Pure argon recommended; 10 - 20 lpm (20 - 40 cfh) or more depending on volume of enclosure to be purged.
- An efficiently sealed system, using dams & root gap tape coverage, is essential practice.
- Back-purge residual oxygen level to be monitored throughout the welding operation, and controlled to <500ppm (0.05% max),
- Suitable purge & re-purge periods required, eg. after tack-weld grind-out, to ensure full restoration of back-purge quality.
- Excessive gas flow rate may result in turbulence and reduced purging efficiency. Flow rate should be reduced for final section of root weld seam weld, to avoid weld pool suck-back and underbead concavity.
- Back-purge to be continued throughout deposition of initial 10mm thickness of weld metal.
- Nitrogen inclusion in gas mix adds supplementary effectiveness to Ar+N_2 torch gas shielding, though might be considered a secondary and expensive option, in view of the volume of gas consumed during prolonged purging.
- The use of pure nitrogen for purging is also an option although care is required to ensure adequate purging because of the lower density of nitrogen compared to argon.
- An oxygen monitor is recommended for all joints so that oxygen content of purge can be confirmed prior to welding.

ǂ Nitrogen works to avoid nitrogen losses from the weld pool, raise root deposit PRE_N and Critical Pitting Temperature.

3.5. Arc energy (heat input) control

Low heat input welding, for weld deposit and HAZ enhanced cooling rate, are essential for
- Appropriately balanced weld metal & HAZ corrosion resisting microstructures
- Avoidance of 'damaged' microstructure and/or 3rd phase precipitation effects.

Heat input controlled via limitation in Arc Energy level, calculated from:

$$\frac{\textbf{Welding current (A) x Arc voltage (V)}}{\textbf{Travel speed (mm/s) x 1000}} = \textbf{kJ / mm}$$

- For manual welding travel speed is the key area of heat input control because as speed increases heat input decreases.

3.6 Recommended root pass weld practice

Root pass:

- 2.4mm GTAW filler wire (1.6mm for material thicknesses ≤ 3mm)
- Moderately higher Amps should be selected to combine
  - as **high** a level of filler wire addition, as is practicable, to maximise root bead thickness
  - a **fast** welding travel speed (typically 40 – 50 mm/min).

Note: Avoid low Amps to avoid slower and hotter welding.
- Aim to deposit root pass using heat inputs in the range 1.0 - 1.5kJ/mm; higher heat input may be tolerated on thicker material with an appropriate increase in filler addition.

2nd 'Cold Pass' Layer:

- Full width weave single pass weld layer recommended; not a 2-bead layer.
- Controlled weave, root thickening layer only.
- Use modestly increased Amps (eg. +10%). Excessive Amps cause root reheat damage.
- Use faster travel speed (typically 80 – 100 mm/min)

Aim: Heat input in range 75 – 100% of root deposit level.
As pipe section/wall thickness* decreases *lower heat input welding is essential.

3.7. Interpass temperature control

- Relates to weld zone background temperature.
- Directly influences cooling rate of weld bead being deposited.
- Measure using contact pyrometer, for precise control.
- Precisely at point of next arc strike-up.
- Immediately prior to every weld run not just every weld layer.

-

Aim: operate with minimum interpass temperature, within practicable limits.
- Inter-run forced cooling, using dry compressed air? Safe practice;
- Forced cooling is operating at temperature levels significantly below those associated with microstructural transformation and embrittlement.
  - avoids moisture contamination of weld joint and deposit surfaces,
- Maximum interpass temperature selection based on component section thickness. Typical recommendations are given in Figure 3.

10"Ø Sch 80 (273mm x 15.09mm)	150^0C
6"Ø Sch 40S (168mm x 7.11mm)	100^0C
2"Ø Sch 10S (60.3mm x 2.77mm)	50^0C

Figure 3: Maximum recommended interpass temperature for different pipe dimensions.

3.8. Weld Run-Out-Length (ROL)

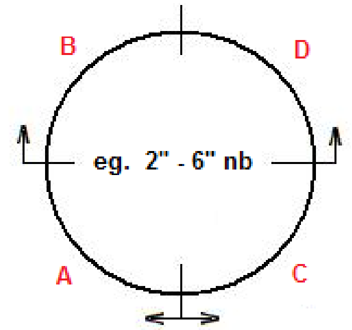
Manual GTAW root welding:
- travel speed is relatively slow (eg. 45 - 50mm/min),
- heat builds up in the joint ahead of the advancing weld pool,
- weld zone background temperature increase progressively,
- weld deposit / HAZ cooling rates progressively slow down as the ROL increases, adversely affecting weld quality,
- excessive weld ROL leads to damaging effect on weld deposit microstructure.

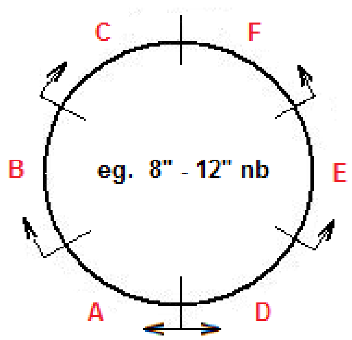
ie. with unlimited welding ROL, weld zone quality progresses from a condition of being reliable to being questionable.

Practical solution?

- Controlled Run-Out-Length discipline:
  - weld via a series of equal length segment runs,
  - provides positive procedural guidance to the welder,
  - full circumferential weld length made up of a series of near-identical packages of controlled cooling rate weld deposit & HAZ.

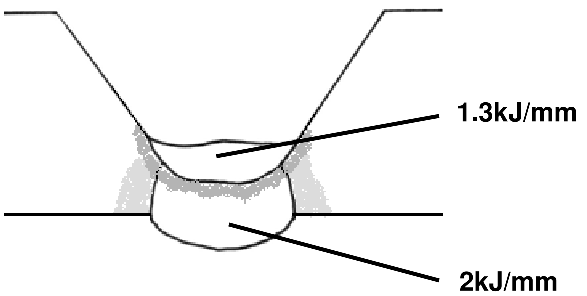
Mixed run-out-length weld run segments should be avoided.





3.9 Factors involved in the balanced deposition of root weld beads

Questionable approach

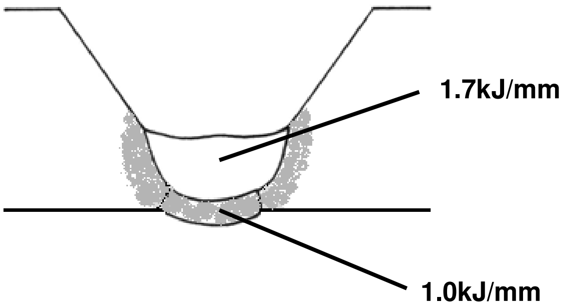


Root bead:
- welding amperage too low,
- root gap too wide,
- excessive filler wire addition,
- slow welding travel speed.

Result:
Excessively high heat input, resulting in a 'defective' as-deposited weld microstructure.

2nd pass:
- correct welding parameters used,
- adequately controlled root bead reheating, but the root bead already irreversibly 'damaged'.

Questionable approach



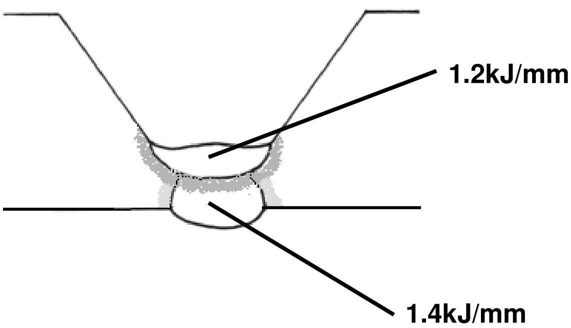
Root bead:
- excessive welding travel speed,
- insufficient filler wire addition,
- 1.6mm Ø filler wire, instead of recommended 2.4mm.

Result:
Excessively thin root bead, susceptible to reheat 'damage' from follow-up weld layer.

2nd pass:
- welding amperage >10% increase recommended,
- excessive weld weaving and filler wire addition,
- low travel speed, high heat input weld deposit.

Result: Destructive reheating of root bead & HAZ.

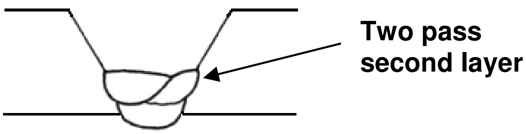
Recommended approach



Root bead:
- Moderately higher welding amperage,
- High 2.4mm filler wire addition aids:
  - optimised weld pool analysis,
  - weld pool chilling effects,
  - deposition of thick reheat resistant root bead.

Result: Faster travel speed, controlled heat input weld.

2nd pass:
- Single layer, weld root thickening deposit,
- Higher travel speed capability,
- Lower kJ/mm heat input level,
- Retention of satisfactory root bead & HAZ structure and corrosion resistance.



Two pass second layer risks overheating of the root zone a controlled single pass second layer is preferred.

4 Weld metal / HAZ pitting corrosion testing

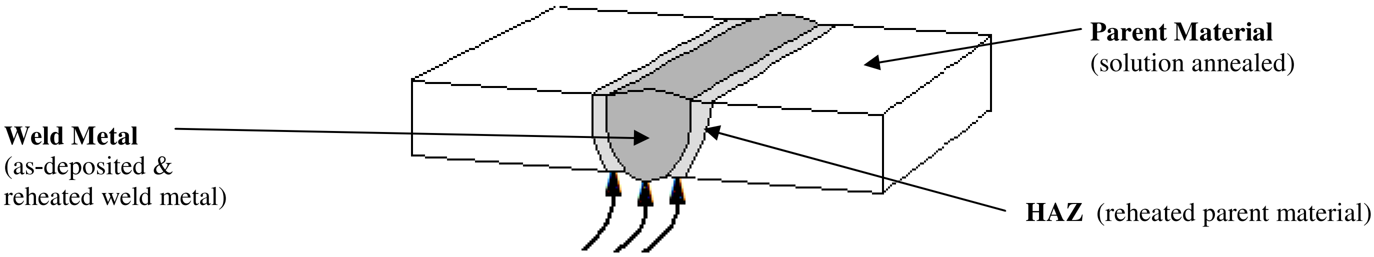
4.1 General

With the fabrication of duplex stainless steels, particularly for applications involving in-service exposure to a combination of chloride ions, temperature and pressure, there is a need to establish, at the welding procedure qualification stage, that butt joints can demonstrate an appropriate level of resistance to pitting attack. This applies particularly to the weld /HAZ surfaces which would be in direct contact with the process media in service, usually a pipe or vessel single-side weld root under-surface. The ASTM G48 Method A test [2] has been universally adopted as a basis for butt joint evaluation:
- concentrated acid ferric chloride solution ; accelerated corrosion potential,
- short term exposure period ; offers rapid assessment for QC purposes.

The aim is to obtain a positive commentary on a weld's root zone microstructural resistance to chloride ion attack. It should be recognised that the 'G48A' type weld test is not intended to relate specifically to field welds' corrosion resistance performance under prolonged exposure to offshore oil / gas recovery process media. Some aspects of the test procedure and assessment of results, which would not be relevant to production weld manufacture, are necessary to obtain a clear indication of a weld's general fitness-for-service.

Designed specifically for evaluation of standard '300 series' stainless steels and Ni-base parent materials, the G48A test lacks some of the refinements in specimen preparation and testing procedure that are necessary with the testing of weld joints:

- to meet client's specific testing and criteria of assessment requirements.
- to accommodate the more complex geometry of weld test specimens,
- a wider range of material microstructures.



Weld / HAZ under-surface of primary significance

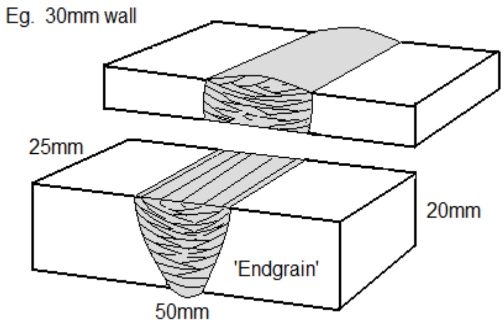
The Welding Institute [3] reported on recommended best practice and criteria of acceptability, which became the basis on which the testing of welds could be realistically approached. Subsequently, further refinements in practice have been introduced in an attempt to ensure reliability of the assessment process.

The following sections (4.2 to 4.4) which incorporate TWI's recommendations can be regarded as key steps in obtaining a meaningful indication of a weld's pitting resistance when assessed using the ferric chloride accelerated corrosion test method.

4.2 Test specimen preparation

Full wall thickness test pieces with dimensions of 25mm of weld length x 50mm transverse section. The four saw-cut faces, together with all edges and corners should be polished to a 1200 SiC Grit finish to eliminate any micro-groove sites for preferential crevice attack as a preliminary to pitting by the aggressive chloride media. The weld root undersurface to be left in the as-welded condition, ie. no dressing or polishing.

For material thicknesses in excess of ~ 20mm, it is recommended that the upper section of the weld be machined off, to reduce specimen thickness to minimise influence of any preferential attack on the susceptible endgrain surfaces. The specimen's top face should be polished to the same standard as the other cut edges.



4.3 Test method

The testing practice outlined in ASTM G48 Method A should be followed, with the added proviso that the ferric chloride solution should include the $Na_2EDTA.2H_2O$ additive recommended by TWI, in order to maintain stability of the test solution's activity level.
Test specimen to be fully immersed in the bath, having a temperature as specified by the client, typically ;

22 or **25°C**, for **UNS S31803, S32205** standard duplex, controlled to ±0.5°C.

35 or **40°C**, for **UNS S32750, S32760, S32550** superduplex, controlled to ±0.5°C.

The specification of test temperatures higher than the respective 25°C and 40°C upper limits has been shown:

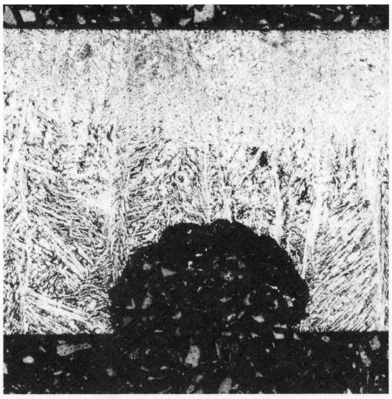
- to approach excessively close to the critical pitting temperature of the respective filler metals,
- to lead to scattering of results, and less meaningful commentary on the weld's pitting resistance capabilities.

Whilst ASTM G48 Method A recommends an exposure period of 72 hours, with the testing of parent materials, for weld test specimens 24 hours is universally recognised as a suitably long enough period.

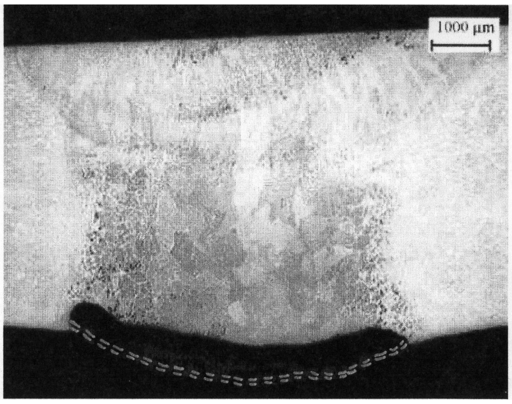
4.4 Assessment of test results

Acceptability of test results is based on two principal criteria: visual examination and weight loss which are discussed in sections 4.4.1 and 4.4.2.

4.4.1 Visual examination
Visual examination is carried out at x20 magnification, to check for evidence of surface attack. Experience has shown that not all incidences of attack are visible on the surface and it may be necessary to include probing for suspected sub-surface cavitation using a sharp instrument.



Visible attack



Attack revealed by probing

Since the G48A test method exposes all 6 faces of the specimen to media exposure, attack may occur:
- at any point where there are sharp changes in surface profile, eg. weld surface ripples, weld bead contact angle with the parent material surface, etc. Hence, the recommendation for fine polishing of weld test piece cut edges in particular.
- on the weld endgrain surface, which exposes the full strata of ‘as cast’ and reheated microstructural areas associated with individual weld beads and HAZ’s, Whilst there are strong arguments in favour of regarding the incidence of pitting attack on faces other than the weld root surface under test, as irrelevant:
  - endgrain attack is regarded by some clients as cause for questioning the consistency ofprocedural control employed throughout the welding operation.
  - the absence of pitting on the root under-surface, but exhibited on the endgrain, may be cause for demands for a re-test on a duplicate specimen.

4.4.2 Weight loss determination
The assessment of welds, has progressed to include measurement of tested specimen weight loss. Since testing involves full immersion of the specimen in the ferric chloride bath, all surfaces are exposed to attack. Originally, a maximum of 20mg was recommended by The Welding Institute, on the basis that weight losses up to this level could be attributed to general corrosion, and attack of specimen surface irregularities . Above this level, weight loss was considered to include specific pitting attack of susceptible microstructural regions. The NORSOK Standard M-601 [4] incorporated a maximum weight loss requirement of $4g/m^2$ (again, based on the whole specimen surface area) which has become an oil/gas industry standard. (Note: TWI’s 20mg weight loss, with a 20mm thick test specimen, equates to $3.6g/m^2$). The 1200 grit finish recommended by TWI is essential to minimising secondary surface attack weight losses, which might result in rejection of otherwise acceptable weld joints.
The endgrain surface requires particularly careful polishing, since numerous areas of pitting-susceptible reheated microstructure are automatically exposed during testing. In addition, it is recommended that prior to testing, specimens are pickled & re-passivated, using a 20%HNO_3 + 5%HFsolution, for 5 min at 60^0C, as recommended by NORSOK standard
- Pickling removes a surface ‘skin’ and any detachable material associated with the weld root and cap surfaces, eg. fine oxide, slag particles, etc.
- Re-passivation, by the oxidising component of the solution, aims to replace the protective oxide layer.
- A further 24 hours standing in free atmosphere is recommended to ensure full restoration of the weld’s natural protected surface.

Failure to carry out the thorough specimen preparation recommended jeopardises the opportunity to meet weight loss acceptance criteria specified by the client. This is illustrated by the following data from tests on a 219mm Ø x 15.9mm wall thickness GTAW weld in Zeron 100 pipe, which did not exhibit pitting on the surface specifically under examination.

Test 1: Specimen, polished to 600 grit finish, resulted in significant endgrain attack and weld rejection on the grounds of unacceptable weight loss.

Pitting Corrosion - ASTM G48-A: 2003								
	Dimensions [cm]	Surface Prep [Grit]	Time [hr]	Temp [°C]	Wght Loss [mg]	Wght Loss [g/cm²]	Pitting	Assessment Method
001:Weldment	5.39x 2.70x 1.88	600	24	40.0	132.4	$2.2x10^{-3}$	Y	Probing

Item 01: PICKLED IN 20% HNO3 + 5% HF FOR 5 MINS AT 60 DEG C.
PITTING NOTED ON THE WELD CAP.
PITTING NOTED ON THE WELD END GRAIN ON BOTH 5.39 X 1.88 FACES.
NO PITTING NOTED ON TEST SURFACE.

↖ $22g/m^2$

Test 2: Duplicate specimen polished to 1200 grit finish, showed absence of endgrain attack and reduction in weight loss to an acceptable level. (In this instance, the weld cap surface pitting was ignored on the grounds that this was not a surface under examination.)

Pitting Corrosion - ASTM G48-A: 2003								
	Dimensions [cm]	Surface Prep [Grit]	Time [hr]	Temp [°C]	Wght Loss [mg]	Wght Loss [g/cm²]	Pitting	Assessment Method
001:Weldment	5.00x 2.34x 1.84	1200	24	40.0	12.1	$2.4x10^{-4}$	Y	PROBING

Item 01: PICKLED IN 20% HNO3 + 5% HF FOR 5 MINS AT 60 DEG C
PITTING NOTED ON THE WELD CAP.

↖ $2.4g/m^2$

5. Pitting corrosion test evaluation of suspect weld microstructures

Experience with the QC testing of duplex/superduplex weld qualification butt joints has progressed, with some parties, in the direction of assessing weld metal/HAZ fitness-for-purpose by focussing on answers to 2 key questions concerning the weld zone:

- Can it exhibit a satisfactory level of fracture toughness?
- Does it exhibit appropriate resistance to pitting corrosion attack of the key surface(s)?

This approach is embodied in ASTM A923 [5], which specifies test procedures designed to establish the extent that intermetallic phases detected in a weld's microstructure affect its toughness and pitting corrosion resistance.
Whilst this standard was developed primarily for the testing of duplex and superduplex stainless steel parent materials, in the finished heat treated condition, its relevance to the evaluation of welds is recognised.

ASTM A923 specifies the test procedures and requirements in three stages:

Test Method A, prescribes the polishing and electrochemical etching of appropriate pieces of welded material. This allows the balance of microstructural phases, and presence of intermetallic precipitations to be established. Where weld microstructural quality is viewed as questionable, further mechanical and/or corrosion tests are specified, depending on the weld performance aspect of key importance to the project. For example:

Test Method B prescribes Charpy V-Notch impact tests at -40°C, to check for toughness:
2205 grade duplex s/s*: Weld metal : 34J (25ft-lb) minimum
(10 x 10mm) HAZ : 54J (40ft-lb)
(The required energy level for sub-size specimens is reduced in direct proportion to its cross-sectional area relative to a full-size specimen).

*Whilst the current, 2006, issue of the standard does not include specification for 25%Cr type superduplex s/s weld metal & HAZ, requirements for a similar level of weld toughness might be considered appropriate.

Test Method C prescribes a ferric chloride pitting corrosion test procedure, of a similar nature to that of ASTM G48A, to evaluate 22%Cr and 25%Cr duplex/superduplex microstructures at 22°C and 40°C respectively. Again, whilst the current issue of A923 quotes requirements for 22%Cr weld metal only, those quoted for 25%Cr parent material could be regarded as appropriate also for 25Cr weld metal. Assessment of performance is on the basis of weight loss rate.

It should be noted that the acceptance criteria are distinctly tighter than those for G48A tests; ie. maximum acceptable corrosion rate = 10mg/square decimetre/per day (10 mdd). In comparison with the 4g/square metre/day required by NORSOK standard.
Eg. For a 50 x 25 x 10mm test piece, maximum acceptable weight loss after 24h exposure:

NORSOK: $4g/m^2$ equates to 16mg maximum acceptable weight loss,
ASTM A923: 10mdd equates to 4mg maximum acceptable weight loss.

The tighter weight loss limit places increased emphasis on test specimen preparation, particularly since A923 does not permit a prior pickling & re-passivation stage.

It should be noted that the principles of ASTM A923 have been usefully employed, by some oil / gas clients, to affect a resolution of problems involved with weld procedure qualification test failures, for example:

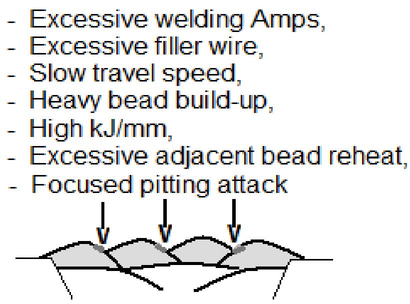
- weld ferrite phase test results falling outside the typical 35–65% range specified.
- weld/HAZ hardness levels exceeding the 320HV maximum (for 22%Cr standard duplex) or 350HV maximum (for 25%Cr superduplex) values specified by oil companies for sour service applications.

6 Pitting attack of secondary surfaces

Since the whole of the test specimen is immersed in the ferric chloride solution, all 6 surfaces are exposed to attack. Clearly, with regard to the 5 secondary surfaces, any features which create the conditions which invite crevice or pitting attack will raise questions of their relevance to a butt welds' quality.

In addition to specimen preparation measures emphasised with regard to the endgrain surfaces, weld cap bead profiles can have a bearing on final test results.

Weld capping pass procedure should aim to avoid depositing narrow peaky beads, which create points of acuity, which act as notches that focus attack, leading to surface pitting.



7 Recommendations

7.1 Welding procedure

A disciplined approach at all stages of Weld Procedure Qualification test welding is essential for the achievement of weld joints capable of demonstrating compliance with the challenging requirements of oil / gas fabrication specifications. Welding procedural discipline at the testing stage lays the foundation for reliable production welding practice at the fabrication stage.

7.2 G48A testing procedure

The G48A ferric chloride testing stage, in principle, is a fundamental examination of the corrosion resistance of the weld metal & HAZ material microstructure. As such, the elimination of test specimen surface features that detract from the accuracy of measurement of the level of pitting attack, which can be solely attributable to the microstructure's integrity, is an essential aid to evaluation of a weld's reliability, ie:

- thorough polishing of all the test specimen's cut edges, corners and faces,
- pickling, to eliminate all superfluous root and cap surface 'debris',
- re-passivation of all surfaces to re-establish the material's natural protective skin.

8. References

1. PC Gough & JCM Farrar "Factors affecting weld root run corrosion performance in duplex and superduplex pipework" *Duplex Stainless Steels '91 Conference*, p1009-1025, **Vol 2**, Beaune France 28-30 October (1991).
2. ASTM G48–03, *Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution.*
3. The Welding Institute (UK), 1993 "*Recommended Practice for Pitting Corrosion Testing of Duplex Stainless Steel Weldments by Use of Ferric Chloride Solution*".
4. NORSOK Standard M-601, Edition 5, April 2008, "*Welding and inspection of piping*".
5. ASTM A 923–06, "*Standard Test Methods for Detecting Detrimental Intermetallic Phase in Duplex Austenitic / Ferritic Stainless Steels*".