

Baseline Report

ITER Vacuum Handbook Attachment 1 - Welding

This Attachment 1, to the ITER Vacuum Handbook, relates to welding of vacuum boundaries and outlines the procedures for documentation, qualification, approval and testing.

This Attachment is based on the international standards ISO 9606, ISO 15614 and ISO 15609, additional requirements are specified to achieve the high integrity and reliability of the vacuum systems to ensure the required ITER machine reliability – Additional requirements are identified in this document.

The requirements are designed to complement codes which may be used. Where requirements differ in general the more stringent standard should be applied or advice sort from ITER.

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ITER Vacuum Handbook

Attachment 1 Inspection and Qualification of Welded Joints

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1 Scope

This Attachment relates to welding of vacuum boundaries and outlines the procedures for documentation, qualification, approval and testing.

Whilst this Attachment is based on the international standards ISO 9606, ISO 15614 and ISO 15609, additional requirements are specified to achieve the high integrity and reliability of the vacuum systems to ensure the required ITER machine reliability. Specifically this Attachment is more stringent in places than the standards in the range of approval for joint types, mechanical testing and acceptance criteria.

The requirements are designed to complement codes which may be used. Where requirements differ in general the more stringent standard should be applied or advice sort from ITER.

2 The Welding and Inspection Plan

Before fabrication can commence the *supplier* shall prepare for approval a weld plan. The weld plan is a drawing which cross references each welded joint to a supporting Welding Procedure Specification (WPS).

3 Welder and operator Qualification

The welder qualification is intended to show the competence of the welder/operator for implementing the specified WPS.

Welder qualification shall be in accordance with ISO 9606 or equivalent standards agreed in advance. For welding operators ISO 14732 shall be used.

Other standards may be approved by ITER on submission of documentation detailing the equivalence between the proposed standards and the standards quoted herein. All standards and documentation pertaining to equivalence shall be submitted in English and must be agreed in advance of welding operations.

The *supplier* shall establish and maintain a list of qualified welders and operators. This list shall include their individual identification and range of welds for which they are qualified.

4 Applicable Standards

The latest revisions of the standards listed in Table 4-1 shall be applied in the procedure, qualification, and acceptance testing etc. of any welding process and form, where applicable, part of this attachment. Alternative national standards may be submitted for approval but they must meet the minimum technical requirements of this Attachment. Alternatives must be formally accepted through written communication before welding can commence.

Where this attachment is more stringent than the standards, this document takes precedence. Where specified in this document, additional requirements to or requirements differing from the quoted international standards have been highlighted ***in bold italics***.

ISO 15607	Specification for the qualification of welding procedures for metallic materials – general rules
ISO 15614	Specification and qualification of welding procedures for metallic materials-welding procedure test
ISO 15609	Specification and qualification of welding procedures for metallic materials – Welding procedure specification
ISO 17637	Non-destructive examination of fusion welds. Visual examination.
ISO 4063	Welding and allied processes – Nomenclature of processes and reference numbers.
ISO 3452	Non-destructive testing. Penetrant testing.
ISO 17638, ISO 9934	Non-destructive examination of welds. Magnetic particle examination of welds
ISO 17636	Non-destructive examination of welds. Radiographic examination of welds.
ISO 17640	Non-destructive examination of welds. Ultrasonic Examination.
ISO 9606-1	Qualification test of welders – Fusion welding – Part 1: steels.
ISO 9606	Qualification test of welders – Fusion welding – Part 2: aluminium and aluminium alloys.
ISO 14344	Welding and allied processes – Flux and gas shielded electrical welding processes – Procurement guidelines for consumables.
ISO 5817	Fusion welded joints in steel, nickel, titanium and their alloys (beam welding excluded) – Quality levels for imperfections.
ISO 14732	Welding personnel. Approval testing of welding operators
ISO 9712	Non-destructive testing - Qualification and certification of NDT personnel
ISO 22825	Non-destructive testing of welds - Ultrasonic testing - Testing of welds in austenitic steels and nickel-based alloys
ISO 10380	Corrugated metal hoses and hose assemblies

Table 4-1 Standards relating to welding

5 Welding Procedure Specification

The Welding Procedure Specification (WPS) is a document which details all the variables which must be defined to produce a weld of acceptable quality. The qualification of the WPS shall be performed in accordance with this Attachment.

Each WPS shall detail each type of weld and shall include, but not be limited to, the following in accordance with ISO 15609:

- Identification of equipment manufacturer
- Equipment calibration records
- Examiner or test body
- WPS number
- Parent material(s), defining which joint element is comprised of a given material
- Filler material(s): classification, type, trade name, flux, diameter of electrode, rod, or wire

- Joint sketch and weld run sequence
- Range of qualified thicknesses and/or diameters
- Welding position
- Welding process (in accordance with ISO 4063)
- Welding technique (single, multipass etc)
- Groove or edge preparations (cleaning, degreasing, jigging etc)
- Shielding and backing gas (composition and flow rates)
- Welding equipment parameters which may include:-
 - AC or DC
 - Polarity
 - Current range
 - Voltage range
 - Pulsed welding parameters
 - Tungsten electrode diameter and type
 - Nozzle diameter
- Backing: method and type, materials and dimensions
- Back gouging: method
- Heating: pre-heat temperature, interpass temperature, post weld temperature
- Drying and preservation temperatures for covered electrodes (if applicable)

Additional Parameters for automatic welding may include:

- Welding equipment specification
- Tool and programme numbers (where applicable)
- Travel speed range
- Wire feed speed range
- Arc Voltage Control parameters

For special processes (remote welding etc) additional information may be required.

6 Welding Procedure Qualification Record

The Welding Procedure Qualification Record (WPQR) is used to record all the relevant data from the welding of test pieces in the qualification of the WPS.

- The qualification of the WPS provides proof that the defined welding process, will achieve a weld of acceptable quality. The welding and testing of this must be witnessed by an ITER recognised Independent Inspection Authority.

All welding data and results from the required non-destructive and destructive testing shall be documented using a Welding Procedure Qualification Record (WPQR). It can also be called Welding Procedure Approval Record (WPAR).

6.1 Qualification of the Welding Procedure Specification.

An existing Welding Procedure Qualification Record (WPQR or WPAR) is acceptable if the following conditions are met:

- The test must have been performed in the same environment as proposed for production, using the same welding technique, process, joint configuration and welding equipment (for mechanised welds)
- The allowable ranges are the same with regard to essential variables.
- The related Preliminary Welding Procedure Specification (pWPS) has been qualified in accordance with ISO 15614
- The test must have been witnessed by an ITER recognised Independent Inspection Authority

Weld produced for qualification must be performed by suitably qualified welders.

The *supplier* must also demonstrate that the welding equipment and plant use for qualification is properly maintained and calibrated in accordance with the relevant operation and maintenance schedules.

6.2 Extent of Approval

6.2.1 Material Groups

For differing grades of stainless steel (304, 304L, 316, 316L and 316LN-IG), cross qualification can be accepted for manual welds when 316L filler is used. Cross qualification is not acceptable for automatic welds. Transition welds joining dissimilar materials other than those listed above must have specific qualification tests performed.

6.2.2 Base Materials

Qualification on production metal type and grade is mandatory. There is no requirement for the use of material from the production heat number for qualification of the WPS.

ISO9001:2000 (clause 7.5.2) states that welding is always a special process. Welding processes commonly used in the manufacture of ITER components with a vacuum classification (according to ITER Vacuum Handbook) and their classification in the context of ITER are listed in Table 1. For special welding processes (Table 6-2) Production Proof Samples shall be manufactured from the production heat number.

Name	N [†]	AWS ^φ	Special (Yes/No)
Gas metal arc welding	131 135	GMAW	No
Manual Gas Tungsten Arc Welding	141	GTAW	No
Automatic, or mechanized Gas Tungsten Arc Welding			Yes
Electron Beam Welding	51 511	EBW	Yes
Laser Beam Welding	521 522	LBW	Yes
† N reference numbers as specified in ISO 4063 (in the European Union published as EN ISO 4063)			
φ AWS reference codes of the American Welding Society are commonly used in North America			

Table 6-1 Welding Processes**6.2.3 Thickness Range****6.2.3.1 Thickness Range for Welds Excluding Fillet and Branch**

The qualification of a welding procedure test on thickness t shall include qualification for thickness in the ranges given in Table 6-2 in accordance with ISO 15614.

Thickness of test piece 't' (mm) (where 't' is the thickness of the thinner material)	Range of Approval ^{1,2} (Dimensions in mm)		
	Parent material thickness		Deposited weld metal thickness for each process 's'
	For single run or single run from both sides	Multi-run	
$t \leq 3$	0.5 t to 2 t		Max. 2 s
$3 < t \leq 12$	0.5 t (3 min) to 1.3 t	3 to 2 t	Max. 2 s
$12 < t \leq 20$	0.5 t to 1.1 t	0.5 t to 2 t	Max. 2 s
$20 < t \leq 40$	0.5 t to 1.1 t	0.5 t to 2 t	Max. 2 s when $s < 20$ Max. 2 t when $s \geq 20$
$40 < t \leq 100$		0.5 t to 2 t	Max. 2 s when $s < 20$ Max. 200 when $s \geq 20$
$100 < t \leq 150$		50 to 2 t	Max. 2 s when $s < 20$ Max. 300 when $s \geq 20$
$t > 150$		50 to 2 t	Max. 2 s when $s < 20$ Max. 1.33 t when $s \geq 20$
1 - When impact requirements are specified but impact tests have not been performed, the maximum thickness of qualification is limited to 12 mm.			
2 - The range of approval may have to be reduced in order to avoid hydrogen cracking.			

Table 6-2 Range of Approval for material thickness and weld deposit thickness– all welds

6.2.3.2 Thickness Range for Fillet Welds

The qualification of a welding procedure test on thickness t shall include qualification for thickness in the ranges given in Table 6-3 in accordance with ISO 15614.

Thickness of test piece 't' (mm)	Range of approval (Dimensions in mm)		
	Material thickness	Throat thickness	
		Single run	Multi-run
$t \leq 3$	0.7t to 2 t	0.75 a to 1.5 a	No restriction
$3 < t < 30$	3 to 2 t	0.75 a to 1.5 a	No restriction
$t \geq 30$	≥ 5	†	No restriction
Note 1: a is the throat thickness of the test piece Note 2: Fillet welds cannot be qualified by Butt welds † For special applications only. Each throat thickness has to be proofed separately by a welding procedure test			

Table 6-3 Range of qualification for material thickness and throat thickness of fillet welds

6.2.3.3 Thickness Range for Branch Pipes (Diameter Range)

The qualification of a welding procedure test on diameter D shall include qualification for diameters in the following ranges give in Table 6-4 in accordance with ISO 15614.

Diameter of test piece $D^{1,2}$ (in mm)	Range of approval
$D \leq 25$	0.5 D to 2 D
$D > 25$	$\geq 0.5 D$ up to plates (25 mm min)
1) D is the outside diameter of the pipe or the outside diameter of the set-on branch pipe 2) Approval given for plates also covers pipes when outside diameter is > 500 mm	

Table 6-4 Range of approval for pipe and branch connections

6.2.4 Range of Approval of Welded Joints

Lip weld and Automatic socket welds shall be qualified on actual size within nominal material specification tolerances. Pre-weld /socket/spigot gap shall be adequate to preclude post-weld abutment contact and minimise weld stress. The range of approval for other types of joint is given in Table 6-5.

6.2.5 Range of Approval Welding Consumables

All consumables shall be certified to a standard acceptable to the ITER IO (e.g. ISO 14344). In the case of manual welding processes the approval range of filler materials covers other filler metals as long as they are in the same range and chemical composition.

In the case of automatic and semi automatic welding processes the welding consumables used for qualification shall be the same batch as those used for production welds. Following any change during production, weld samples shall be welded and examined prior to the continuation of production with the new batch of consumables. Qualification using filler does not qualify autogenous (fusion welding with out filler material) welds or vice versa.

6.2.6 Welding Processes

In all cases, any change in the welding process will require a requalification of the process. In addition, in the case of automatic welding any change to the welding equipment will require requalification.

6.2.7 Welding Position

Welds for qualification shall be done in local conditions similar to the local conditions where the production weld will be made. Local access to the test piece (in terms of welder access) and the orientation of the test piece (relative to the welder) shall be similar to those for the production weld for which they qualify.

Type of Joint in Approval Test Piece			Range of Approval											
			Butt welds on plate				T Butt welds on plate		Fillet weld on plate	Butt welds on pipe		Fillet weld on pipe	Branch welds on pipe	
			Welded from one side		Welded from both sides		Welded from one side	Welded from both sides		Welded from one side			Set on	Set through
			With backing	No backing	With gouging	No gouging				With backing	No backing			
Butt weld on plate	Welded from one side	With Backing	✓	✗	Δ	Δ	✗	✗	✗	✗	✗	✗	✗	✗
		No Backing	Δ	✓	Δ	Δ	✗	✗	✗	✗	✗	✗	✗	✗
	Welded from both sides	With gouging	✗	✗	✓	Δ	✗	✗	✗	✗	✗	✗	✗	✗
		No gouging	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗
Butt weld on pipe	Welded from one side	With backing	Δ	✗	Δ	Δ	✗	Δ	✗	✓	✗	✗	✗	✗
		No backing	Δ	Δ	Δ	Δ	Δ	Δ	✗	Δ	✓	✗	✗	✗
T Butt weld on plate	Welded from one side		✗	✗	✗	✗	Δ	Δ	✗	✗	✗	✗	✗	✗
	Welded from both sides		✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗
Fillet weld	Plate		✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗
	Pipe		✗	✗	✗	✗	✗	✗	Δ	✗	✗	✓	✗	✗
Branch weld in pipe	Set on		✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗
	Set through		✗	✗	✗	✗	✗	✗	✗	✗	✗	✗		✓
Key: ✓ Indicates the weld for which the WPS is approved in the approval test Δ Indicates those welds for which the WPS is also approved ✗ Indicates those welds for which the WPS is not approved														

Table 6-5 Range of approval for type of joint

6.3 Non –Destructive Examination

Supplier's inspectors shall be competent in accordance with ISO 9712.

6.3.1 Examination

After post weld heat treatment and prior to destructive testing, test pieces shall be examined by the following:

- Visual examination (in accordance with ISO 17637)
- Dye Penetrant testing (in accordance with ISO 3452) or Magnetic particle testing (in accordance with ISO 9934)

Inspection using Photothermal camera is permitted in the case where the manufacturer has qualified the method/acceptance criteria prior to the weld qualification

- Radiographic examination (in accordance with ISO 17636)

and/or

- Ultrasonic examination (in accordance with ISO 17640 and ISO 22825 for austenitic steels and nickel alloys)

For a pipe or plate of 2 mm (or less) wall thickness, the method of examination shall be agreed prior to examination.

6.3.2 Acceptance Criteria

Defects which are detected by the relevant non-destructive examination method shall be assessed in accordance with ISO 5817 level B. In particular acceptance criteria are detailed in Table 6-6. Table 6-6 is in accordance with ISO 5817 however contains additional requirements for production vacuum boundary welds.

	Defect Type	Permitted maximum
Planar Defects	Cracks or lamellar tears	Not permitted
	Lack of root fusion	
	Lack of side fusion	
	Lack of inter-run fusion	
	Lack of root penetration	
Solid inclusions	Slag inclusions - individual	20% of t or 2 mm, which ever is smaller
	Slag inclusions - Group	Aggregate length not to exceed t in a length of 12 t, except when the distance between successive indications exceeds 6L where L is the longest indication in the group
	Inclusions – <i>Tungsten</i> or Copper	Not permitted
Cavities	Isolated pores - round	Diameter <20% t or 2 mm, whichever is smaller
	Gas pore uniformly distributed porosity	1% for single layer (2% for multi-layer) by area where the area of the radiograph to be considered is the length of the weld affected by the porosity times the maximum thickness of the weld
	<i>Elongated pores - wormholes</i>	<i>Not permitted</i>
	<i>Linear Porosity</i>	<i>Not permitted</i>
Profile defects	<i>Under cut</i>	<i>Some intermittent undercut permitted. Depth not to exceed 0.5 mm for t > 3 mm or 10% for t < 3 mm. Under cut to blend smoothly with the parent material.</i>
	Incompletely filled groove, sagging. Root concavity, shrinkage groove	0.05 t or 0.5 mm, which ever is smaller. Weld thickness shall not be less than the parent plate thickness
	Excess penetration - pipe	Not greater than 5% of the pipe internal diameter up to 2 mm max.
	Excess penetration – plate	t = 0.5 to 3 mm: , h ≤1 mm+10% b t > 3mm: h ≤1 mm+20% b max 3mm.

		h=height of excess penetration on backside of plate and b the width
	Excess weld material	Not greater than 10% weld width
	Misalignment	Not greater than 10% of the parent material thickness
	Fillet leg length (asymmetry)	Unequal leg length should not exceed 20% of the fillet throat thickness
	Burn through	Not permitted
Other	Root oxidation	Not permitted where a backing purge gas is specified in the WPS

Table 6-6 Acceptance levels**6.4 Destructive Tests****6.4.1 Test Specimens**

The number of test specimens that shall be subjected to destructive testing is given in Table 6-7 in accordance with ISO 15614.

TEST SPECIMEN	No of Tests
<u>BUTT WELD</u>	
Transverse Tensile (room temp.)	2
Root Bend (for t <12mm)	2
Face Bend (for t <12mm)	2
Side Bend (for t >12mm)	4
Transverse Tensile (design temp. if required by tech. spec.)	1
Impact test (for t ≥12 mm one set from weld metal and one set from HAZ if required by tech. spec).	2
Macro-examination (with photo)	1
Micro-examination x 200 (if required by tech spec.)	1
Hardness test survey	1
Burst test†	1
<u>FILLET WELD</u>	
Fracture Test	1
Macro-examination (with photos)	4
Micro-examination x 200 (if required by tech. spec.)	2
Hardness Survey	2
<u>T-BUTT/BRANCH CONNECTION</u>	
Macro-examination (with photos)	4
Micro-examination x 200 (if required by tech. spec.)	2
Hardness Survey	2
<u>SOCKET/LIP WELD*</u>	
Macro-examination (with photos)	4
Micro examination x 200 (if required by tech. spec.)	2
Hardness Survey	2
† Longitudinal butt weld on bellows (or flexible) tube to ISO 10380	

Table 6-7 Number of destructive test specimens**6.4.2 Test Results**

Unless specified differently in Table 6-8 destructive testing and test results shall comply with ISO 15614.

<i>Bend test (stainless steel and nickel alloy only)</i>	<i>The bend angle shall be 180° round a former of diameter 2t, where t is the thickness of the specimen. The bend test specimen shall have no open defects exceeding 2 mm measured in any direction on the convex surface after bending.</i>
<i>Micro - Examination</i>	<i>In general micro-examination shall only be required for welds which form part of the vacuum boundary or are in contact with cryogenic liquids. If required micro-examination tests shall be specified in the technical specification.</i>
<i>Macro Examination</i>	<i>For lip welds, penetration shall be 0.7t where t is the thickness of the thinner material.</i>

Table 6-8 Acceptable test results

6.4.3 Qualification for Welds Under Stressed Applications.

Additional destructive tests to those listed in Table 6-7 to qualify welds under stressed applications may be required as defined in the technical specification.

7 Production Welds

Production welds shall be performed to qualified procedures by qualified welders.

The WPS shall be available for reference by welders or welding operators, by the responsible welding engineer and by the authorised inspector.

The contractor must also demonstrate that the welding equipment and plant is properly maintained and calibrated in accordance with the relevant operation and maintenance schedules.

7.1 Inspection of Fusion Welded Joints

After post weld heat treatment welds shall be subject to the following tests:

- Visual examination (in accordance with ISO 17637)
- Dye Penetrant testing (in accordance with ISO 3452) if permitted[†]. (Inspection using Photothermal camera is permitted in the case where the manufacturer has qualified the method/acceptance criteria prior to the weld)
- Radiographic examination (in accordance with ISO 17636)
and / or
- Ultrasonic examination (in accordance with ISO 17640 and ISO 22825 for austenitic steels and nickel alloys)

[†] See ITER Vacuum Handbook Section 7.1.4.

The range of wall thickness and preferred volumetric examination method is given in Table 7-1 .

Defects which are detected by the relevant non-destructive examination method shall be assessed in accordance with Table 6-6.

For all VQC 1A, VQC 2A water boundaries and vacuum boundary welds which become inaccessible, 100% volumetric examination of production welds shall be performed, unless a method of pre-production proof sampling is approved.

For all other vacuum boundaries, volumetric examination of 10% of production welds shall be performed unless a method of pre-production proof sampling is approved. In the event of failures, this shall be increased to 100% examination of the batch, defined as same welder/same WPS/ same weld. Acceptance criteria are specified in Table 6-6

On welds where it is specified that volumetric examination be performed and radiography or ultrasonic inspection is not possible, Production Proof Sampling is required.

Wall Thickness	Preferred Volumetric Examination Method
Wt < 12 mm	Radiography
12 mm > wt < 19 mm	Radiography & Ultrasonic
wt > 19 mm	Ultrasonic

Table 7-1 Range of wall thickness and preferred volumetric examination method

7.2 Production proof samples

Welds where radiography or Ultrasonic testing is impractical (e.g. welds that are not full penetration butt welds) must be covered by Production Proof Sampling (PPS). Each PPS will only represent a specific type of weld and must use the same materials, thickness and set-up as the production weld.

For VQC 1 and 2 vacuum boundary welds a PPS must be welded during the same shift as the production welds and by the same welder using the same equipment to be representative of the production welding.

If more than one welder welds the production welds, each must perform a PPS. PPS's are required each shift production welding is being performed to represent the welds performed on that shift.

For VQC 3 and 4 vacuum boundary welds a PPS shall be welded for each welder performing the production welds.

PPS's should be sectioned and macro examined in four places (including one stop/start area). Photographs of the macros giving the date the PPS was welded, the welder's identity and identifying the production welds it is covering must be included in the final documentation package.

An ITER representative will normally witness PPS welding and all PPS macros shall be reviewed. Operations with witness and hold points to facilitate this must be incorporated in the Work Schedule.

As the PPS is a representative sample, rejection of the macro will result in rejection of all welds covered by this PPS.

7.3 Helium Leak Testing of Production Welds

100% of vacuum sealing welds (VQC 1A, 2A, 3A, 4A) shall be subject to helium leak testing in accordance with the requirements and procedures of the ITER Vacuum Handbook.

7.4 Repair by welding of production welds

No weld repair shall be performed without qualification of the welding procedure. Welding procedures used for welding repair shall be qualified in accordance with this document.

8 Documentation

All quality assurance documentation required by this procedure shall form part of the delivery to ITER, and shall include:

- Weld plans
- WPS's
- WPQR's and test reports
- Welder qualification's and test reports
- PPS test reports
- Production weld test reports
- Reports on weld repairs
- Non-Conformance Reports