PETROBRAS	TECHNICAL SPECIFICATION	Nº. I-ET-3010.00-1200-955-P4X-001
	CLIENT: SRGE	SHEET: 1 of 63
	PROJECT:	CC:
	AREA:	-
DPP-SRGE	TITLE: **WELDING**	INTERNAL
		ESUP

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I N D E X O F R E V I S I O N S

REV.	DESCRIPTION AND/OR REVISED SHEETS
0	ORIGINAL
A	GENERAL REVISION
B	REVISION OF 5.7.2, 5.7.6 AND G.3
C	GENERAL REVISION
D	REVISION OF 2.2 AND 5.1.3.4
E	INCLUSION OF SPECIFIC REQUIREMENTS FOR CARBON STEEL FOR STRUCTURE, SPECIFIC REQUIREMENTS FOR 3.5% NICKEL STEEL, AND GENERAL REVISION

	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E	REV. F	REV. G	REV. H
DATE	AUG/28/18	05/06/2020	10/12/2020	April 22nd 2021	Dec 27th 2021	Dec 28th 2021			
DESIGN	ESUP	ESUP	ESUP	ESUP	ESUP	ESUP			
EXECUTION	MARCHON	MARIANO	UQ0O	UQ0O	UQ0O	UQ0O			
CHECK	MARIANO	NISGOSKI	CSM5	CSM5	CSM5	US1O			
APPROVAL	JUVENTINO	MEYRELLES	BEX1	BEX1	BEX1	BEX1			

SUMMARY

1 INTRODUCTION

This technical specification, in addition to other specifications and codes referred to in Section 2, defines the requirements for all fusion welding operations performed at any part of the Unit, including topside parts and components, hull parts and components, marine systems, as well as any production plant and utilities parts and components. It also includes, but is not limited to, all structures, equipment (both static and dynamic), piping and pipelines, including those supplied as packages.

The requirements herein listed shall be applied along with all the requirements from the applicable Design Codes and IOGP S-705 (welding of pressure containing equipment and piping, supplementary specification to API RP 582), so that the most stringent requirement shall always prevail.

The requirements herein listed are applicable to all players performing such related activities within the scope of the contract, including manufacturers, packagers, main contractor, subcontractors, suppliers, sub suppliers, integrators, constructors, and all technical personnel involved. Within the scope of this document, they are all referred to as being a SELLER.

2 NORMATIVE REFERENCES

The following documents contain requirements that are applicable to the fusion welding operations and shall be followed as applicable.

2.1 CLASSIFICATION SOCIETY RULES

SELLER shall perform the work in accordance with the requirements and rules of the Classification Society (CS).

CS Rules may only be waived upon the formal approval from the CS itself and from BUYER.

2.2 CODES AND STANDARDS

The following codes and standards include provisions which, through reference in this text, constitute provisions of this technical specification. The latest issue of the references shall be used unless otherwise agreed.

Other recognized standards may be used, provided it can be shown that they meet or exceed the requirements of the standards referenced bellow.

- API RP 582 – Welding Guidelines for the Chemical, Oil, and Gas Industries
- ASME B31.3 – Process Piping
- ASME B31.4 – Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids
- ASME B31.8 – Gas Transmission Distribution and Piping Systems
- ASME BPVC Section II Part C – Welding Rods, Electrodes and Filler Metals
- ASME BPVC Section VIII – Rules for Construction of Pressure Vessels

- ASME BPVC Section IX – Welding and Brazing Qualification
- ASTM A262 – Standard Practices for Detecting Susceptibility to Intergranular Attack in Austenitic Stainless Steels
- ASTM A370 – Standard Test Methods and Definitions for Mechanical Testing of Steel Products
- ASTM A380 – Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems
- ASTM A578 – Standard Specification for Straight-Beam Ultrasonic Examination of Rolled Steel Plates for Special Applications
- ASTM E92 – Standard Test Methods for Vickers Hardness and Knoop Hardness of Metallic Materials
- ASTM E527 – Standard Practice for Numbering Metals and Alloys in the Unified Numbering System (UNS)
- AWS A3.0 – Standard Welding Terms and Definitions
- AWS A5.01 – Welding Consumables – Procurement of Filler Metal and Fluxes
- AWS A5.1 – Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding
- AWS A5.4 – Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding
- AWS A5.5 – Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding
- AWS A5.7 – Specification for Copper and Copper-Alloy Bare Welding Rods and Electrodes
- AWS A5.9 – Specification for Bare Stainless Steel Welding Electrodes and Rods
- AWS A5.11 – Specification for Nickel and Nickel-Alloy Welding Electrodes for Shielded Metal Arc Welding
- AWS A5.14 – Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods
- AWS A5.17 – Specification for Carbon Steel Electrodes and Fluxes for Submerged Arc Welding
- AWS A5.18 – Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding
- AWS A5.20 – Specification for Carbon Steel Electrodes for Flux Cored Arc Welding
- AWS A5.23 – Specification for Low-Alloy Steel Electrodes and Fluxes for Submerged Arc Welding
- AWS A5.28 – Specification for Low-Alloy Steel Electrodes and Rods for Gas Shielded Arc Welding
- AWS A5.29 – Specification for Low-Alloy Steel Electrodes for Flux Cored Arc Welding
- AWS A5.34 – Specification for Nickel-Alloy Flux Cored and Metal Cored Welding Electrodes
- AWS D1.1 – Structural Welding Code – Steel
- AWS D10.10 – Recommended Practices for Local Heating of Welds in Piping and Tubing
- ISO 6507-1 – Metallic Materials – Vickers Hardness Test – Part 1: Test Method
- ISO 8501-1 – Preparation of Steel Substrates Before Application of Paints and Related Products – Visual Assessment of Surface Cleanliness
- ISO 15156-1 to 3 – Petroleum and Natural Gas Industries – Materials for use in H2S-Containing Environments in Oil and Gas Production
- ISO 15614-5 – Specification and Qualification of Welding Procedures for Metallic Materials – Welding Procedure Test – Part 5: Arc Welding of Titanium, Zirconium and their Alloys

- ISO 17405 – Non-destructive testing – Ultrasonic Testing – Technique of Testing Claddings Produced by Welding, Rolling and Explosion
- ISO 17781 – Petroleum, Petrochemical and Natural Gas Industries – Test Methods for Quality Control of Microstructure of Ferritic/Austenitic (Duplex) Stainless Steels
- IOGP S-705 – Supplementary Specification to API Recommended Practice 582 for Welding of Pressure Containing Equipment and Piping (version 1.01 of Jun/2021)
- SSPC-SP 10 – Near-White Metal Blast Cleaning
- SSPC-SP 11 – Power-Tool Cleaning to Bare Metal
- WRC 452 – Recommended Practices for Local Heating of Welds in Pressure Vessels

Governmental codes, regulations, ordinances, or rules applicable to the equipment in Brazil shall prevail over the requirements of above specification, including reference codes and standards and/or these engineering specifications, only in those cases where they are more stringent.

2.3 REFERENCE TECHNICAL SPECIFICATIONS

- I-ET-3010.00-1200-970-P4X-003 – REQUIREMENTS FOR PERSONNEL QUALIFICATION AND CERTIFICATION
- I-ET-3010.00-1200-970-P4X-004 – NON-DESTRUCTIVE TESTING REQUIREMENTS FOR METALLIC AND NON-METALLIC MATERIALS
- I-ET-3010.00-1200-200-P4X-115 – REQUIREMENTS FOR PIPING FABRICATION AND COMMISSIONING
- I-ET-3010.00-1200-540-P4X-001 – REQUIREMENTS FOR PRESSURE VESSELS DESIGN AND FABRICATION
- I-ET-3010.00-1200-940-P4X-002 – GENERAL TECHNICAL TERMS

2.4 CONFLICTING REQUIREMENTS

In case of conflicting information between this Technical Specification and the referred applicable standards, the most stringent requirement shall prevail.

The requirements stated in this Technical Specification are intended to be aligned with IOGP S-705 (and API RP 582) or, in some cases, most stringent. Any contradictory requirement between this Technical Specification and IOGP S-705 shall be formally consulted by means of a Technical Query.

In case of conflicting information between this specification and other specific BUYER's Document (Data Sheet or Equipment List), the BUYER technical representative shall be formally consulted through a Technical Query.

Failure to proceed as indicated above may result in repair work at the expenses of the SELLER.

3 DEFINITIONS AND ABBREVIATIONS

3.1 DEFINITIONS

Definitions are in accordance with the technical specification I-ET-3010.00-1200-940-P4X-002 – GENERAL TECHNICAL TERMS, along with the definitions from AWS A3.0 (Standard Welding Terms and Definitions).

Main general terms used throughout this specification that can be added to the definitions are as follows:

Welding Procedure Qualification Record (PQR): The PQR is a record of the welding data and variables used to weld a test coupon and the test results used to qualify the welding procedure. The purpose of the PQR is to establish the properties of the weldment.

Welding Procedure Specification (WPS): The WPS provides direction to the welder while making production welds to applicable code requirements.

Clad: Coating of corrosion resistance alloy (CRA) metallurgically bonded to a less noble base metal (usually carbon steel), to improve its corrosion resistance.

Weld Overlay: A clad coating process that deposits a CRA on the base metal surface by welding.

Heterogeneous Welding: Welding with the application of external filler whose metallurgical composition is substantially different from that of the base metals.

Autogenous Welding: Welding with no additions of filler metal, where the weld pool is composed solely by the fusion and dilution of the base metals.

Dissimilar Welding: Welding which involves the joining together of two metals that possess different chemical or mechanical properties, and so are not necessarily a natural fit for each other.

3.2 ABBREVIATIONS

C	Carbon (Steels)
CE	Carbon Equivalent
C-Mn	Carbon-Manganese (Steels)
C-Ni	Carbon-Nickel (Steels)
CRA	Corrosion Resistant Alloy
CS	Classification Society
CVN	Charpy V-Notch
ESW	Electroslag Welding
FCAW	Flux Cored Arc Welding
GMAW	Gas Metal Arc welding
GTAW	Gas Tungsten Arc Welding
HAZ	Heat-Affected Zone
MT	Magnetic Particle Testing
NDT	Non-Destructive Testing
PQR	Procedure Qualification Record

PREN	Pitting Resistance Equivalent Number
PT	Liquid Penetrant Testing (Dye Penetrant Testing)
PWHT	Post-weld Heat Treatment
RT	Radiographic Testing
SAW	Submerged Arc Welding
SMAW	Shielded Metal Arc-Welding
SMYS	Specified Minimum Yield Stregth
SWPS	Standard Welding Procedure Specification (according to ASME BPVC Section IX)
TMCP	Thermo-Mechanical Controlled Processing
UNS	Unified Numbering System for Metals and Alloys (according to ASTM E527)
UT	Ultrasonic Testing
VT	Visual Testing
WPS	Welding Procedure Specification
pWPS	Preliminary Welding Procedure Specification

4 QUALITY REQUIREMENTS

4.1 GENERAL WELDING CONDITIONS

This technical specification shall be used in conjunction with the design, fabrication, assembly, and post fabrication standards, and with standards of additional requirements related to the service conditions of the equipment item or the structure.

Welding shall as a minimum be performed in accordance with IOGP S-705 (and API RP 582) with the additional requirements herein listed.

Where sour service is applicable, all materials and all welding procedures shall also fulfill the requirements of the applicable Part of ISO 15156.

The requirements for welding operation listed in this Section 4 are valid for all of the materials mentioned in Section 5 and all equipment items or structures made from those materials.

Section 5 lists the specific requirements applicable to the various materials mentioned, such as the permitted welding processes, the allowed consumables, preheating, post-heating and heat treatment temperatures, and specific conditions for welding technique of the materials.

All welding requirements which depend on the characteristics of the equipment or structure, such as, for example, details of bevels, joint fit-up, dimensional tolerances, requirements for post weld heat treatment, requirements for inspection, and acceptance criteria of defects, are not replicated in this technical specification. This information is stated in design, fabrication, assembly, and post fabrication standards, as well as within standards of additional requirements related to the service conditions of the equipment item or the structure.

Dissimilar, heterogeneous, and autogenous welding shall be avoided as much as possible. Dissimilar and heterogeneous welding shall follow the requirements in item 5.10.

Welding is not permitted without the required qualification of welders and welding procedures, according to the applicable design code.

To establish the inspection of the finished welds is not the purpose of this technical specification. Only for specific situations, not well covered by the equipment and piping specifications, this document states the inspection required (e.g. NDT for weld overlay).

The methods to perform PMI, hardness and ferrite testing in the production welds shall be as stated in I-ET-3010.00-1200-970-P4X-004 – NON-DESTRUCTIVE TESTING REQUIREMENTS FOR METALLIC AND NON-METALLIC MATERIALS. For hardness testing, also Annex A of this technical specification shall be followed.

4.2 WELDING DOCUMENTS

Welding documents shall be prepared and qualified in accordance with the applicable design, fabrication, and assembly codes.

Prequalified WPSs provided in AWS D1.1 and the standard welding procedure specifications (SWPSs) specified in ASME BPVC Section IX are not acceptable.

Each WPS shall be supported by suitable(s) PQR(s). Each PQR shall have attached on it the following documents, as minimum: base material certificates, consumable certificates, non-destructive testing reports, PWHT reports, laboratory testing reports.

4.3 WELDING PROCEDURE QUALIFICATION

Test specimens for mechanical tests shall undergo dimensional and visual inspection before tests are performed.

When impact testing on heterogeneous welds and dissimilar joints is required, all zones of different chemical composition, such as HAZ and the weld metal, shall be represented by complete set of test specimens with notch located within those zones.

When the design, fabrication or assembly standard requires hardness testing in qualification of welding procedure, the Annex A of this technical specification shall be followed as a minimum. Additional measures may be needed as required by design or service codes and standards.

The application method and brand name of protective varnishes applied to weld bevels shall be evaluated during the qualification of welding procedure, when its removal before welding is not provided.

For pressure containing equipment and piping, the special requirements/testing of Section 11 of IOGP S-705 shall be followed.

Additional requirements regarding the welding procedure qualification are present in Section 5 and in the Annexes of this technical specification.

4.4 PERSONNEL QUALIFICATION AND CERTIFICATION

Personnel qualification and certification for welding and for non-destructive testing shall be in accordance with I-ET-3010.00-1200-970-P4X-003 – REQUIREMENTS FOR PERSONNEL QUALIFICATION AND CERTIFICATION, as applicable to the project.

Welders Performance Reports shall be issued as required I-ET-3010.00-1200-970-P4X-003 – REQUIREMENTS FOR PERSONNEL QUALIFICATION AND CERTIFICATION.

Qualified welders and welding operators shall bear visible identification including name, the stamp number and qualification (allowed welding process, welding position, etc.).

4.5 WELDING PROCESSES AND EQUIPMENT

Welding shall be performed using processes permitted by the design, fabrication and assembly standards of the equipment or structure, as well as Section 5 of this technical specification.

For pressure containing equipment and piping, the acceptable welding processes listed on Table 7 of IOGP S-705 shall be used with the restrictions in Section 5 of this technical specification.

The electric insulation of electrode holders and cables shall be in good conditions, without flaws or unprotected regions, and properly sized for working conditions and personal safety.

The measurement instruments existing in welding power sources shall be calibrated and within the expiration date.

Welding power source, cables, clamps, electrode holder, welding guns and torches, wire feeders, control cables, extension cords, refrigeration unit, auxiliary command and control units coupled to equipment, high-frequency drive for GTAW process, and others that have direct interference in the process or are interdependent shall meet the requirements of NEMA (National Electrical Manufacturers Association) or IEC (International Electrotechnical Commission).

For SMAW, GTAW, GMAW, FCAW processes, it is recommended the use of inverter power sources.

The portable holding oven for keeping low-hydrogen coated electrodes dry shall have electrical resistances to keep the temperature between 80 °C and 150 °C, and to be of exclusive use for each welder. The ovens shall be calibrated.

4.6 WELDING TECHNIQUE

The grounding clamps and cables shall be in good conditions (grounding clamps shall not be homemade). The contact surfaces shall be free of rust and painting.

The welding arc shall always be struck at the bevel, or at appendix plate used for that purpose.

Joints to be welded shall be free of oil, grease, rust, slag, paint, liquid penetrant testing residues, sand, and soot from gas preheating, in an area of at least 25 mm on each side of the edges, both internally and externally.

The bevels and edges shall be cleaned to bright metal, in an area of at least 25 mm on both internal and external sides.

When preparing the bevel, thermal or mechanical cutting irregularities and slag shall be removed.

When gouging by arc-carbon are used, carbon, slag and copper deposits shall be mechanically removed to ensure complete removal of HAZ and contaminants.

Stainless steel, titanium, cupper-nickel alloys, nickel, and nickel-alloy materials shall be stored, handled, and processed completely separated from other materials, in order to avoid the risk of contamination.

Slag removal and cleaning tools shall be made of materials suitable for each base metal.

When required in Section 5, the back purging shall be used from the inside of the equipment or piping until it reaches the lower value between a deposit of 8 mm of weld metal or the thickness of the welded joint.

When liquid penetrant or magnetic particle testing after gouging is required, the surface preparation for the test shall be made by grinding or other machining process.

The welding of socket welds shall be done with GTAW process, with at least two layers (one pass on first layer, two passes on second layer as minimum) and a smooth convex profile.

4.7 WELDING CONSUMABLES

The selection of consumables shall be in accordance with the requirements set forth in Section 5 of this specification. For processes not covered by Section 5, the corresponding specification of ASME BPVC Section II Part C or AWS specification and classification shall be followed. Welding consumables shall be provided with its respective batch certificates.

The packages for coated electrode, rod or rolled wire shall indicate, legibly and without erasures, its brand name, specification, classification, diameter, heat number and manufacturing date.

Filler metals shall present individual identification of its classification. Coated electrode shall have it printed on each one. Rods shall be identified by punch marks at both ends. The rolled wire shall be identified on the reel.

Irregularities or discontinuities in the coating of coated electrodes, such as localized thickness reduction, cracks, damages at the end, lack of adhesion, as well as dimensional deficiencies in length and eccentricity beyond the limits of the specification and core oxidation signs, are unacceptable.

Bare electrodes or rods with oxidization signs are unacceptable.

The packages of coated electrodes and fluxes shall be free from defects that cause contamination or damage to consumables.

When a consumable is used, it shall present the same conditions of receipt, regarding the absence of defects, identification, and condition of the package.

Coated electrodes and low-hydrogen fluxes shall be subjected to drying operations and special handling conditions for keeping them dry. These operations shall be performed as stated by the consumable manufacturers.

For pressure containing equipment and piping, diffusible hydrogen limits for consumables shall not exceed the values stated in Table 8 of IOGP S-705.

4.8 ENVIRONMENTAL CONDITIONS

Welding shall not be performed under rain, snow, wind, and dust in general, unless the joint is protected.

For all welding processes, protection means shall be used to prevent the action of air currents and humidity that may change welding conditions.

4.9 PREHEATING, INTERPASS AND POST-HEATING

Preheating and post-heating shall be applied when required by design codes and Section 5 of this technical specification.

For pressure containing equipment and piping, the maximum interpass temperature shall follow the Table 4 of IOGP S-705/API RP 582 with the restrictions in Section 5 of this technical specification.

Preheating, where required, applies to all welding, tack welding, arc gouging and thermal cutting.

Welding shall not be performed when the part surface, in an area of 150 mm centered on the joint to be welded, is wet or below the established preheating temperature for the material, according to specific conditions in Section 5.

If preheating is not required, the temperature of the surface to be welded shall not be below 10 °C. If this happens, the surface shall be preheated at 20 °C, or as otherwise determined in Section 5.

The post-heating, where required, shall be applied immediately after the completion of welding. The temperature shall not fall below the preheating temperature specified in the WPS.

The preheating and post-heating shall be performed by electrical resistance, induction or by flame. Manual preheating by blowtorch flame may be used, as long as there is no restriction to its use in Section 5. Professionals responsible for the manual heating by flame shall receive prior training, and also shall be guided about the possible metallurgical damage to the different materials to be welded if this operation is poorly executed. The use of cutting nozzle blowtorch in preheating is not permitted.

The preheating and post-heating temperature shall be measured on the base metal, on all joint members, on the opposite side to the heating source whenever possible, at 75 mm from the weld groove. Preheating and temperature control procedures shall be prepared.

NOTE: If flame heating is used, where the temperature may only be measured from the side of the source, heating shall be interrupted for at least 1 minute for every 25 mm of thickness of the piece before it is measured.

The interpass temperature shall be measured on the weld metal, on the region in which the next pass will be deposited. If using temperature indication stick (crayon), when permitted in Section 5, the measurement shall be made in an adjacent area to avoid contamination of the subsequent pass.

Preheating, interpass and post-heating temperatures shall be checked by means of optical or contact pyrometers, taking care so that the instrument adjustment is correlated with the emissivity of the material. The temperature indicating sticks may also be used, as long as it does not conflict with Section 5 of this technical specification.

4.10 INSPECTION AND QUALITY CONTROL

All finished welds shall be 100% visually inspected and evaluated by a Welding Inspector or by Visual Welding Inspector, with the acceptance criteria of the applicable standard of manufacture. This visual inspection shall precede the other non-destructive tests. SELLER shall issue a VT report.

The Welding Inspector shall ensure that the welding variables (preheating, heat input, gas flow and composition, welding position, etc.) provided in WPS remains within the qualified limits throughout the production welding.

4.11 WELD REPAIRS

The same inspection requirements needed for welded joints shall be applied to their repairs. Non-destructive testing shall always be performed on 100% of the surface on the excavated area before the release of the repair filling.

The requirements of Annex B for welding repair shall be followed.

NOTE: For pressure containing equipment and piping, see items 11.9 and 12.11 of IOGP S-705.

4.12 POST WELD HEAT TREATMENT (PWHT)

PWHT shall be applied when required by the design or fabrication and assembly codes of equipment or structure and shall comply with the conditions prescribed by those standards.

NOTE: For pressure containing equipment and piping, see item 9 (mainly 9.11 and 9.12) of IOGP S-705.

PWHT shall be performed by electrical heating, induction, or in furnace.

The zone to be heated to PWHT temperature shall cover the temporary weld areas referring to auxiliary assembly devices, even when they have been removed.

When performing PWHT located in the circumferential welds, or in which the component has the freedom of expansion during treatment, the conditions set forth in AWS D10.10 or WRC 452 shall be met.

4.13 AUXILIARY ASSEMBLY DEVICES

Auxiliary assembly devices, when permitted by the fabrication and assembly standard of equipment or structure, shall comply with the requirements of this technical specification and the following conditions:

a) welds of auxiliary assembly devices, tack welds and other temporary welds shall be considered definitive welds for purposes of application of the requirements of this technical specification.

b) the number of auxiliary assembly devices restricting transverse contraction of weld shall be minimized, and devices limiting angular deformation of the welded joint and allowing transverse contraction shall be preferred.

c) chemical composition of the devices shall be similar to the pieces being welded, so that the same welding procedure from the main joint shall be used to guide the welding of the auxiliary devices.

d) welds of auxiliary assembly devices shall be deposited at least 25 mm away from the edges of the bevel or directly on the faces of the bevel.

e) auxiliary assembly devices shall be removed before any PWHT and prior pressure testing and shall not be removed by impact (e.g. hammering).

f) the area of temporary weld, after it has been removed, the surface shall be ground smooth and inspected with MT or PT and present no undercuts, pores, cracks, thickness reduction or incomplete removal.

4.14 MARKING OF WELDED JOINTS

Welded joints shall be marked with the identification number of the welder or welding operator.

In joints welded by more than one welder or welding operator, the mark shall distinguish who performs each of the passes.

Punch marking is permitted only for carbon steel with nominal thickness greater than 6.4 mm, at a minimum distance of 25 mm from the edge of the weld. All other materials shall be identified by an industrial marker, as long as its composition does not contaminate the material.

For oil and gas pipelines and for hull structural parts, punch marking is not allowed.

4.15 SAFETY IN WELDING

Any welding service shall only be performed if it complies with the safety requirements provided in the applicable Health, Safety, and Environment (HSE) procedures.

In welding services in confined space, an additional assessment shall be made by HSE team regarding the protection of welding team.

5 MATERIALS

5.1 CARBON STEEL (STRUCTURE)

5.1.1 Introduction

For welding of quenched and tempered steels and TMCP steels, the welding procedure qualification shall be performed with test coupons of the same steel supply condition.

For welding procedures qualified with more than one welding process, impact test specimens shall cover all processes.

Unless otherwise specified by the welding qualification code/standard/rules, impact testing temperature on welding procedure qualification shall be equal to or lower than that one required for base metal. For example: -40 °C for EH grades, -20 °C for DH grades and so on.

5.1.2 Welding Technique

Root quality of full penetration welds shall be ensured by backgouging or by use of temporary backing strip, as applicable. The use of permanent backing shall be avoided.

After the use carbon-arc gouging, such as for backgouging, for repair, or for temporary attachments removal, the surface shall be ground in order to remove any carbon contamination.

5.1.3 Welding Processes

Permitted welding processes shall be in accordance with item 4.5 of this technical specification with the following restrictions and notes.

5.1.3.1 SMAW

a) Electrodes with AWS classification EXX10, EXX11, EXX12, EXX13, EXX14, EXX24 and EXX27 shall not be used.

5.1.3.2 GTAW

a) No restrictions.

5.1.3.3 GMAW

a) GMAW with short-circuit transfer mode and globular transfer mode is not permitted.

b) GMAW with spray transfer mode is permitted only for tertiary structures.

5.1.3.4 FCAW

a) FCAW-S (self-shielded) is not permitted, except when toughness (impact testing) is not required for the structure.

b) The use of filler metal with specification/classification different from that one applied in the welding procedure qualification is not permitted.

c) The use of filler metal with brand name different from that one applied in the welding procedure qualification is not permitted when toughness (impact testing) is required.

5.1.3.5 SAW

a) The semiautomatic (manually held) process is not permitted.

b) The use of welding flux with brand name different from that one applied in the welding procedure qualification is not permitted.

5.1.3.6 ESW/EGW

a) BUYER's approval is required.

5.1.4 Welding Consumables

Welding consumables shall be according to AWS Specification and Classification.

Welding consumable shall matches/overmatches the mechanical properties of base metal, such as:

a) Base metal with SMYS ≤ 360 MPa: E70XX, ER70X-X, E7XT-X and so on

b) Base metal with SMYS > 360 MPa: E80XX, ER80X-X, E8XT-X and so on

For structures with toughness (impact testing) requirement, the welding consumables shall be acquired with impact testing at temperature equal to or lower than that one required in the welding procedure qualification.

Diffusible hydrogen limits for consumables shall not exceed:

a) Base Metal with SMYS ≤ 360 MPa: 16 ml/100g

b) Base Metal with SMYS > 360 MPa: 8 ml/100g

5.1.5 Preheating and Interpass Temperature

Preheating for welding of metallic structures shall be determined in accordance with AWS D1.1.

Interpass temperature for carbon steel welds shall not exceed 315 °C. For carbon steel welds with toughness (impact testing) requirement, interpass temperature shall not exceed 250 °C.

5.1.6 Post-Heating

It is usually not required, except when there is risk of hydrogen cracking, as for thick plates and high restriction. In this case, approximately 200 °C with baseline time of 1 min/mm of thickness of joint, but no less than 15 minutes shall be applied.

5.1.7 Post Weld Heat Treatment

It is usually not required.

5.1.8 Weld Repair

The same welded area shall not be repaired more than two times.

5.2 CARBON STEEL (PRESSURE CONTAINING EQUIPMENT AND PIPING)

5.2.1 Introduction

The requirements herein stated applies to carbon steels ans carbon-manganese steels.

It shall be observed the additional requirements of standards and specifications for quenched e tempered steels, micro-alloyed steels, high strength and low alloy (HSLA) steels, for steels classified under P-Number 1 Group 3 or Group 4, P-Number 10 (except for 10H, 10I, 10J, 10K) and P-Number 11B.

When qualifying weld procedures for high strength pipe components (API 5L X56 and above, as well as the equivalent material specifications for accessories, such as ASTM F694 Grade F56 and above) the qualification test coupon shall use as base material the exact same strength grade as will be used in production welding.

5.2.2 Welding Technique

For high strength steels (tensile strength ≥ 490 MPa), the HAZ formed by thermal cutting processes shall be removed by machining or grinding.

When impact testing is required, the multiple passes welding shall be performed with straight and thin passes, not exceeding three times the diameter of the core of coated electrode for SMAW process or 12 mm for the other welding processes.

5.2.3 Welding Processes

Permitted welding processes shall be in accordance with item 4.5 of this technical specification with the following restrictions and notes.

5.2.3.1 SMAW

a) Electrodes with ASME/AWS classification EXX10, EXX11, EXX12, EXX13, EXX14, EXX24 and EXX27 shall not be used.

5.2.3.2 GTAW

a) No restrictions.

5.2.3.3 GMAW

a) GMAW with conventional short-circuit transfer mode and globular transfer mode is not permitted.

5.2.3.4 FCAW

a) The use of filler metal with specification/classification different from that one applied in the welding procedure qualification is not permitted.

b) The use of filler metal with brand name different from that one applied in the welding procedure qualification is not permitted when toughness (impact testing) is required.

5.2.3.5 SAW

a) The use of welding flux with brand name different from that one applied in the welding procedure qualification is not permitted.

5.2.4 Welding Consumables

Welding consumables shall be according to ASME BPVC Section II Part C or AWS Specification and Classification, as applicable.

5.2.5 Preheating and Interpass Temperature

Joints shall be preheated to temperatures equal to or above those indicated in Table 1.

Preheating temperatures of design codes or fabrication standards may be applied, at BUYER's discretion, replacing the values given in Table 1.

Table 1 – Minimum Preheating and Interpass Temperatures for C and C-Mn Steels

Carbon equivalent – CE (1)	Calculated thickness of welded joint (2)		
	e ≤ 20 mm	20 < e ≤ 30 mm	e > 30 mm
CE_{IIW} ≤ 0.41%	10 ºC	10 ºC	10 ºC
0.41% < CE_{IIW} ≤ 0.45%	10 ºC	10 ºC	100 ºC
0.45% < CE_{IIW} ≤ 0.47%	10 ºC	100 ºC	125 ºC
0.47% < CE_{IIW} ≤ 0.50%	100 ºC	125 ºC	150 ºC

Note 1: The carbon equivalent (CE_{IIW}) shall be calculated according to the following formula, based on the elements content values obtained from mill certificates (chemical analysis) or from laboratory testing.

$$CE_{IIW} = \%C + \frac{\%Mn}{6} + \frac{\%Cr + \%Mo + \%V}{5} + \frac{\%Cu + \%Ni}{15}$$

Note 2: The thickness of welded joint shall be calculated according to Figure 1.

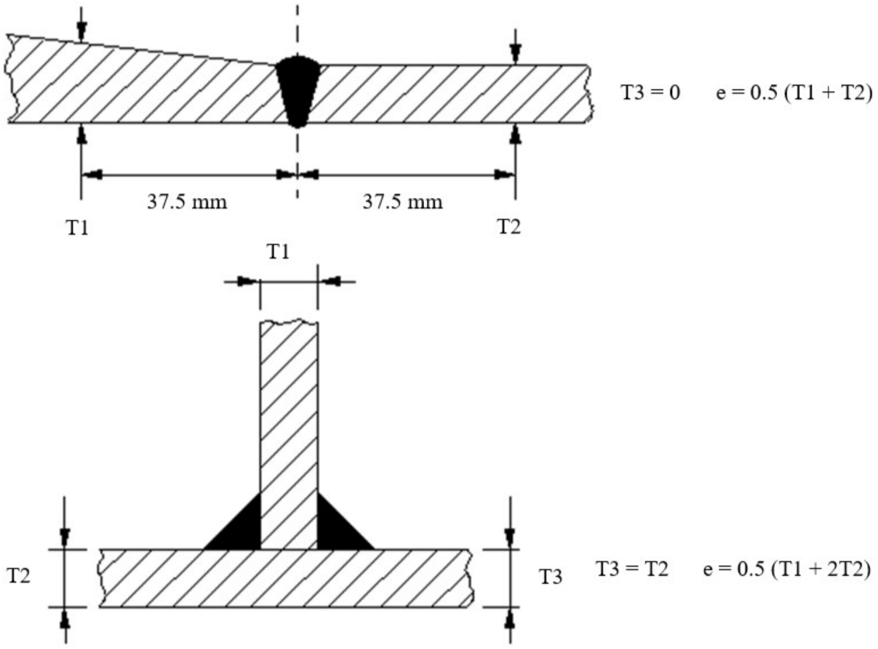


Figure 1 – Details for Determining Weld Thickness

Interpass temperature for carbon steel welds shall not exceed 315 °C. For carbon steel welds with toughness (impact testing) requirement, interpass temperature shall not exceed 250 ºC.

It is recommended that the manual heating by gas flame (blowtorch) is limited in pipes or equipment's shells with thickness up to 25.4 mm and nominal diameter up to 10''.

5.2.6 Post-Heating

It is usually not required, except when there is risk of hydrogen cracking, as for thick plates and high restriction. In this case, approximately 200 °C with baseline time of 1 min/mm of thickness of joint, but no less than 15 minutes shall be applied.

5.2.7 Post Weld Heat Treatment

PWHT shall comply with the applicable design code and/or service standards (e.g. sour service according to ISO 15156).

NOTE: For pressure containing equipment and piping, see items 9.11 and 9.12 of IOGP S-705.

5.2.8 Weld Repair

The same welded area shall not be repaired more than two times.

The repair shall be performed in multiple passes, always trying to promote tempering of the previous passes.

NOTE: For pressure containing equipment and piping, see items 11.9 and 12.11 of IOGP S-705.

5.3 AUSTENITIC STAINLESS STEEL

5.3.1 Introduction

This Section includes the austenitic stainless steels with microstructure fully austenitic or austenitic-ferritic, such as:

a) Steels from AISI 3XX Series (304, 316, 317, 321, 347, 310) standard or conventional.

b) Low carbon steels from AISI 3XXL Series, used in corrosive services with carbon content lower than 0.030%.

c) Controlled carbon steels from AISI 3XXH Series, used in services at high temperature, with carbon contents ranging from 0.04% to 0.1%.

d) Casting steels for general use and for use at high temperatures.

5.3.2 Welding Technique

The fabrication of stainless steel piping and equipment shall be made in a segregated and protected area, preferably in a shed separated from other materials.

Carbon arc cutting and gouging and oxyfuel cutting is not permitted. Thermal cutting shall be preferably performed by plasma or laser, and the surface shall be ground in order to remove any signs of oxidation and irregularities.

The root opening shall be slightly wider than the one commonly used for carbon steels, because the root tends to close more often, which may result in lack of fusion. Austenitic stainless steels have thermal expansion coefficient approximately 50% greater than the carbon steel, and lower thermal conductivity. These factors generate high residual stress and higher tendency to distortion (warping) in the welded joint.

In welding of austenitic stainless steel, some details of extreme importance and shall not be overlooked in order to reduce the risk of solidification cracking. This includes joint preparation, surface cleaning, quantity of material deposited per pass, aiming the width/depth ratio equal to one, slight convexity of passes, and suitable welding speed in order to avoid weld pool in drop form. Figure 2 illustrates the formation of cracks due to the width/depth ratio (A) (B) (C) and concavity (D).

The risk of crater-type hot cracks may be mitigated by training welders on torch outlet. The profile shall be slightly convex, as shown in Figure 3.

It is recommended that the surface of the parts is protected from adherence from spatter and other projections resulting from the weld, especially when the GMAW and FCAW processes are used.

The part of the auxiliary assembly device touching or welded to the equipment shall have the same P-Number of the base metal, according to the classification of ASME BPVC Section IX, or otherwise be coated with the consumable specified for welding of base metal in deposits of at least two layers. Contamination with carbon (carburizing followed by precipitation), iron and iron oxide are detrimental to corrosion resistance.

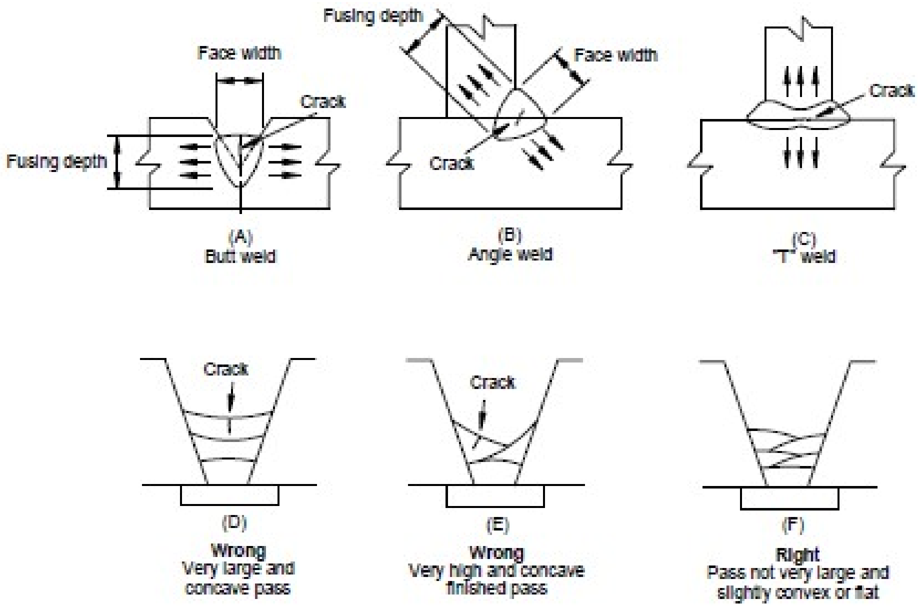


Figure 2 – Examples of Solidification Cracks

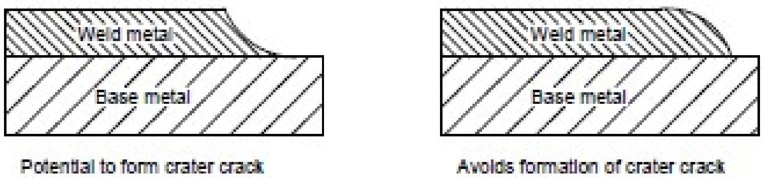


Figure 3 - Examples of Torch Outlet Profile

The welding shall be performed with straight passes and low heat input. The heat input shall not exceed 2 kJ/mm. For stabilized austenitic stainless steels (321 and 347 grades), the heat input shall not exceed 1.5 kJ/mm.

Slag and flux residues shall be completely removed after welding.

Slag removal, cleaning and cutting tools shall only be used for these materials and shall meet the following conditions:

a) Slag removal and cleaning tools shall be made of stainless steel or coated with this material.

b) The cutting discs shall be made of aluminum oxide with nylon core or of fiberglass.

Contamination by contact with sulfur, zinc, copper, tin, lead, among others, may irreversibly compromise the austenitic stainless steels when exposed to high temperature.

Upon completion of welding and before the start of operation, soaps and detergents used in bubble, liquid penetrant and industrial marker residue tests shall be eliminated. Temperature indicating sticks (crayons) shall not be used, being recommended the contact thermometer for temperature control.

Back purging with inert gas shall always be employed to protect the root side of welds, for all welding processes. Purge gas in the root must be maintained until the 3rd layer of weld or 8 mm, whichever is greater. This internal protection is applicable for butt welds, socket welds, sealing welds as well as for any weld performed on the opposite side when thickness of the base material is below 8 mm (e.g. the welding of an external support in a piping requires gas protection internal to the piping).

Back purging shall ensure the expulsion of all the oxygen in the root zone and no welding is to be started before the oxygen content is less than or equal to 500 ppm. The gas flow varies depending on the joint, but generally is between 10 L/min and 15 L/min.

The weld root must be subjected to visual inspection to determine the oxidation level before any non-destructive testing. It is permitted a maximum degree of oxidation according to Table 10 and Annex C of IOGP S-705.

When purging fails to protect the weld root surface, the weld joint shall be internally pickled and passivated.

The pickling and passivation processes shall be according to ASTM A380. Electrolytic weld cleaning may be used in lieu of chemical pickling, but passivation shall always follow.

External oxidation shall also be removed.

Oxidation removal by mechanical processes may only be permitted where the access is feasible.

Back purging with nitrogen during welding is only permitted after previous review and evaluation from BUYER. The ferrite content in base material, gas purity, and risk of hot cracking after welding shall be evaluated.

5.3.3 Welding Processes

Permitted welding processes shall be in accordance with item 4.5 of this technical specification with the following restrictions and notes.

5.3.3.1 SMAW

a) The use of synthetic consumables is not permitted.

b) For welding of AISI 321 steel, consumable AISI 347 shall be used due to the low transfer of titanium in the process.

c) Whenever the material is exposed to temperature above 538 ºC during fabrication or operation, the consumable shall be acquired according to AWS A5.01 Schedule J, ensuring its bismuth content does not exceed 0.002%.

5.3.3.2 GTAW

a) Besides argon (99.99%), the argon + helium mixture or only helium may be used as shielding gas. The argon + H2 mixture (1 to 3%) may only be used with previous approval from BUYER.

b) When a cored wire specific for GTAW welding (100% argon) is used, any flux residue shall be removed, especially where there is contact with the fluid. The welding may be performed with inert gas, mixtures of those gases, argon + O2 (2% maximum) or argon + CO2 (5% maximum). Other mixtures richer in CO2 may be used, if previously approved by BUYER, and if it is performed the intergranular corrosion test during the welding procedure qualification, according to ASTM A262.

5.3.3.3 GMAW

a) GMAW with conventional short-circuit transfer mode and globular transfer mode is not permitted.

b) Welding may be performed with inert gas, mixtures of those gases, argon + O2 (2% maximum) or argon + CO2 (5% maximum). Other mixtures richer in CO2 may be used, if previously approved by BUYER, and if performed the intergranular corrosion test during the welding procedure qualification, according to ASTM A262.

5.3.3.4 FCAW

a) The use of filler metal with specification/classification different from that one applied in the welding procedure qualification is not permitted.

b) Whenever the material is exposed to temperature above 538 ºC during fabrication or operation, the consumable shall be acquired according to AWS A5.01 Schedule J, ensuring its bismuth content does not exceed 0.002%.

c) The gas may be an argon + CO2 mixture (EXXXTX-4) or only CO2 (EXXXTX-1), as long as it is not observed carburization with pure CO2 during the qualification process. The carbon percentage shall be assessed through chemical analysis and/or intergranular corrosion test, as in ASTM A262.

5.3.3.5 SAW

a) The use of welding flux with brand name different from that one applied in the welding procedure qualification is not permitted.

b) Whenever the material is exposed to temperature above 538 ºC during fabrication or operation, the consumable shall be acquired according to AWS A5.01 Schedule J, ensuring its bismuth content does not exceed 0.002%.

c) Weld fluxes shall be stored and handled so as to avoid contamination. Contamination in stainless steels is critical because it may reduce the corrosion resistance.

d) Flux used in welding of austenitic stainless steel shall be neutral or basic, without deleterious effect to the weld zone.

e) The use of alloyed fluxes is not permitted, except to compensate for loss of alloying elements in the metal transfer.

f) Moisture on plates or in the flux may cause porosity. Wet fluxes shall be re-dried, as indicated by the manufacturer.

5.3.4 Welding Consumables

The consumables shall follow the instructions in Table 2. Alternative consumables may only be used with previous approval from BUYER.

Table 2 – Consumables for Austenitic Stainless Steels

Base Material	SMAW (AWS A5.4)		GTAW/SMAW (AWS A5.9)		FCAW-G (AWS 5.22)		SAW (1) (AWS A5.9)	
	1st option	2nd option	1st option	2nd option	1st option	2nd option	1st option	2nd option
304 / CF8	E308	E308L	ER308	ER308L	E308TX-X		ER308	
304L / CF3	E308L	E347	ER308L	ER347	E308LTX-X		ER308L	
304H (2)	E308H	E308 (3)	ER308H	ER308 (3)	E308HTX-X		ER308H	
CH20	E309	E309Mo E309LMo	ER309	ER309Mo ER309LMo				
310 / CK20	E310	E310Nb	ER310	ER310Nb	E310TX-X		ER310	
316	E316	E316L	ER316	ER316L	E316TX-X		ER316	
316L	E316L		ER316L		E316LTX-X		ER316L	
316H (2)	E316H	E316 (3)	ER316H	ER316 (3)	E316HTX-X		ER316H	
CF8M	E308Mo	E316	ER308Mo	ER316				
CF3M	E308LMo	E316L	ER308LMo	ER316L				
317 / CG8M	E317	E385	ER317	ER385	E317LTX-X		ER317	ER317L
317L	E317L	E385	ER317L	ER385	E317LTX-X		ER317L	
321 / 347 / CF8C	E347		ER347		E347TX-X		ER347	
347H (2)	E347 (3)		ER347 (3)		E347HTX-X	E347TX-X (3)	ER347 (3)	

Note 1: Only the filler metals present AWS classification, with no similar for the flux.

Note 2: E/ER16-8-2 with 1 to 5 FN may be used.

Note 3: Filler metal with carbon content 0.04% minimum.

The minimum ferrite content in the weld deposits shall be 3 FN. For classification 347, it shall be 5 FN minimum.

The maximum content of ferrite shall be lower than 9 FN in steels exposed to high temperature (≥ 370 °C) or in those subjected to at least one PWHT cycle (coating/weld overlay) during fabrication. The measurement of ferrite shall be performed before PWHT.

The ferrite content shall be measured in the welding procedure qualification.

5.3.5 Preheating and Interpass Temperature

Preheating is not required.

The interpass temperature shall be kept as low as possible and not exceed 175 °C, except for the AISI 317L steel, which shall not exceed 120 ºC.

5.3.6 Post-Heating

Post-heating is not required.

5.3.7 Post Weld Heat Treatment

PWHT is generally not required.

5.3.8 Weld Repair

The same welded area shall not be repaired more than two times.

5.4 DUPLEX AND SUPERDUPLEX STAINLESS STEEL

5.4.1 Introduction

For the purpose of this technical specification, Duplex Stainless Steel (DSS) and Super Duplex Stainless Steel (SDSS) are base material with microstructure composed of about 50% ferrite and 50% austenite and characterized by a Pitting Resistance Equivalent Number (PREN), calculated by the following formula:

$$\mathrm{PREN} = \%\mathrm{Cr} + 3.3\,(\%\mathrm{Mo} + 0.5\,\%\mathrm{W}) + 16\,\%\mathrm{N}$$

DSS is also known as 22Cr Duplex, and the most usual base material specification is:

a) UNS S31803 (EN n° 1.4462), PREN ≥ 30.5

SDSS is also known as 25Cr Duplex, and the most usual base material specifications are:

a) UNS S32750 (EN n° 1.4410), PREN ≥ 37.7
b) UNS S32760 (EN n° 1.4501), PREN ≥ 40 (with W in its chemical composition)

The welding procedure qualification for DSS and SDSS shall consider the additional requirements stated in Section 11 of IOGP S-705 and Annex C of this technical specification.

The welder qualification shall consider the additional requirements of I-ET-3010.00-1200-970-P4X-003 – REQUIREMENTS FOR PERSONNEL QUALIFICATION AND CERTIFICATION.

5.4.2 Weldability

Attention shall be given to the heat input and interpass temperature control, particularly in multi pass welding, due to the risk of carbide precipitation, nitrides and intermetallic phases when kept in the range of critical temperatures.

When welding, the aim is to achieve the correct balance between ferrite and austenite in the weld metal and HAZ and to avoid the precipitation of deleterious second phases in the HAZ or weld metal.

The use of consumables with higher Ni content may grant weld metal properties compatible with the base metal. Welding with consumables with a chemical composition that matches the one from the base materials is allowed only when the full welded piece is submitted to a full anneal heat treatment after welding, so that the phase balance is restored in the whole piece.

5.4.3 Welding Technique

The manufacture of pipes and equipment in stainless steels shall be done in segregated and protected area, preferably in a separate workshop.

Carbon arc cutting and gouging and oxyfuel cutting is not permitted.

For plasma cutting, depending on the quality required for the cutting, argon, or argon + H2 mixture may be used with the following combinations: 85/15%, 80/20%, and 65/35%. A higher H2 content will help increase the arc energy resulting in higher cutting speeds and/or larger cutting thicknesses.

For thermal cutting processes (e.g. plasma and laser cutting), after cutting the bevels and edges shall be trimmed (grinding) in 1.0 mm at least.

Also due to the higher viscosity of stainless steel weld puddle in relation to C and C-Mn steels, the preparation shall consider higher joint angle than for those steels, minimizing the risk of lack of fusion.

The preparation and cleaning must consider a range of 50 mm on both sides of the joint. This area must be cleaned by grinding and solvent to remove grease, oxides, paint markers and other contaminants that may be harmful to welding.

The tools for slag removal, cleaning and cutting must be used exclusively for these materials and meet the following requirements:

a) Tools for slag removal and cleaning shall be stainless steel or coated with this material.
b) Cutting discs and grinding must be made of aluminum oxide with soul "Nylon" or fiberglass.
c) Additional precautions must be taken to avoid contamination of the joints during preparation.

It is recommended that the surface of the parts is protected against spatter and other projections resulting from welding, especially when it is used the GMAW process.

Consumables (wires, rods, and electrodes) shall be properly stored in clean, dry place and always handled with clean gloves. The wires shall be cleaned with solvents before use.

The use of spot welding and auxiliary assembly devices shall be detailed in the welding procedure to be submitted for previous approval from BUYER, including the specification of materials to be used in the manufacture of device and the weld consumables to be used.

The part of the auxiliary assembly device in contact or welded to the main part/component (piping, equipment, or structure) shall be of the same P-Number of the base metal (in accordance with the classification of BPVC ASME Section IX) or, alternatively, covered with an equivalent specified consumable welding metal with at least two layers.

The heat input for welding DSS and SDSS weld joints must be conforming to Table 3.

Table 3 – Heat Input for Welding DSS and SDSS

Material	Joint Thickness (t)		
	t ≤ 7 mm	7 < t ≤ 20 mm	t > 20 mm
DSS	0.5 to 1.2 kJ/mm	0.7 to 1.5 kJ/mm	1.0 to 2.0 kJ/mm
SDSS	0.5 to 1.0 kJ/mm	0.7 to 1.2 kJ/mm	1.0 to 1.5 kJ/mm
Note 1: A heat input below the specified increases the cooling rate and may result in low formation of austenite. Note 2: A heat input welding above the specified may cause the precipitation of deleterious phases, reducing the mechanical and corrosion resistance properties. Note 3: For GTAW and PAW processes the heat input values shall be multiplied by 1.2.			

The relationship between the heat input of the root pass and second pass shall be around 85%, as the example shown in Figure 4.

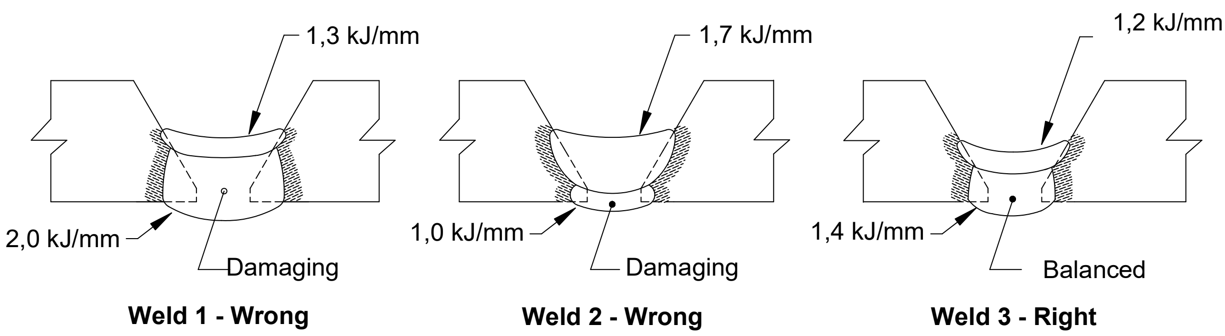


Figure 4 – Heat Input for DSS and SDSS

Field welding by one side shall be performed by the GTAW process in the root pass and second pass, with shielding and purge gases shall be hydrogen-free to prevent cracking and embrittlement of the weld metal.

As nitrogen is an important austenite former and major contributor to the increase in resistance to pitting corrosion, the loss of this element through the weld pool and diffusion from the HAZ to the weld metal can be avoided using shielding and purge gases with nitrogen addition in appropriate percentages.

Back purging shall always be employed to protect the root side of welds, for all welding processes. Purging in the root must be maintained until the 3rd layer of weld or 8 mm, whichever is greater. This internal protection is applicable for butt welds, socket welds, sealing welds as well as for any weld performed on the opposite side when thickness of the base material is below 8 mm (e.g. the welding of an external support in a piping requires gas protection internal to the piping).

Purging shall ensure the expulsion of all the oxygen in the root zone and no welding is to be started before the oxygen content is less than or equal to 500 ppm. The gas flow varies depending on the joint, but generally is between 10 L/min and 15 L/min.

The weld root must be subjected to visual inspection to determine the oxidation level before any non-destructive testing. It is permitted a maximum degree of oxidation according to Table 10 and Annex C of IOGP S-705.

When purging fails to protect the weld root surface, the weld joint shall be internally pickled and passivated.

The pickling and passivation processes shall be according to ASTM A380. Electrolytic weld cleaning may be used in lieu of chemical pickling, but passivation shall always follow.

External oxidation shall also be removed.

Oxidation removal by mechanical processes may only be permitted where the access is feasible.

5.4.4 Welding Processes

Permitted welding processes shall be in accordance with item 4.5 of this technical specification with the following restrictions and notes.

For single-sided joints, root pass and second pass shall be made by the GTAW or PAW process.

For double-sided joints (where the weld root is accessible for gouging with grinding machine), the SMAW and GMAW-P processes may be used for the root pass.

The use of FCAW process is not permitted for DSS and SDSS.

Autogenous welding is only permitted with previous approval from BUYER.

5.4.4.1 SMAW

a) The use of synthetic electrodes is not allowed.
b) Consumables shall be handled as low-hydrogen electrodes, ensuring a diffusible hydrogen content not exceeding 8 ml/100g of deposited weld metal.

5.4.4.2 GTAW

a) Shielding gas: pure argon, argon + N2 (2% maximum) mixture, argon + helium mixture or pure helium.
b) For base material with addition ≥ 0.20% N, argon + N2 mixture shall be used.
c) The purge gas for the root protection must be of the same composition of shielding gas.

5.4.4.3 GMAW

a) GMAW with conventional short-circuit transfer mode and globular transfer mode is not permitted.

b) GMAW is not allowed for the welding of the root pass.

c) Shielding gas: pure argon, argon + N2 (1.5% to 2%) mixture, argon + helium mixture, argon + CO2 (1% to 2%) mixture. The latter only with previous approval from BUYER.

d) The purge gas for the root protection must be of the same composition of gas shielding gas.

5.4.4.4 SAW

a) The use of welding flux with brand name different from that one applied in the welding procedure qualification is not permitted.

b) The welding flux shall not add alloying elements, except for the compensation for losses in the electric arc, which is normal for basic flux with Cr compensation.

c) The welding flux shall be low-hydrogen, ensuring a diffusible hydrogen content not exceeding 8 ml/100g of deposited weld metal.

5.4.5 Welding Consumables

Consumables shall follow the requirements of Table 4.

Table 4 – Consumables for DSS and SDSS

Base Material Type	SMAW (AWS A5.4)		GTAW / GMAW / SAW (AWS A5.9)		Filler Metal PREN (IOGP S-705)
	1st option	2nd option	1st option	2nd option	
S31803	E2209	E2594	ER2209	ER2594	34 ≤ PREN ≤ 40
S32750 / S32760	E2594	-	ER2594	-	40 ≤ PREN ≤ 48 40 ≤ PREN ≤ 45 (sour service)
Note: Additional restrictions about nitrogen, nickel, molybdenum, and sulfur content set forth in Table 3 of IOGP S-704 shall be met.					

5.4.6 Preheating and Interpass Temperature

Preheating is not applicable.

Maximum interpass temperature shall be 150 °C for DSS and 100 °C for SDSS.

5.4.7 Post-Heating

Post-heating is not applicable.

5.4.8 Post Weld Heat Treatment

PWHT is not applicable.

5.4.9 Production Parameter Monitoring by Autonomous System [Recommended Practice]

Welds on duplex and superduplex stainless steels with thickness equal to or greater than 1.5” should be performed with continuous monitoring of the welding parameters.

The following parameters should be continuously tracked and registered by an autonomous system:

a) Welding current

b) Welding voltage

c) Welding speed

d) Preheat temperature

e) Maximum interpass temperature

NOTE: Many commercially available monitoring systems lack the ability to properly track the welding speed and therefore the heat input. In these cases the missing information may be collected by a qualified welding inspector instead.

Weld parameter monitoring should be applied during the weld procedure qualification, during welder/operator performance qualification, and during production welds.

All data generated during production welds and during welder qualification should be collected and compared to the data collected during procedure qualification.

5.4.10 Weld Repair

The same welded area shall not be repaired more than two times for DSS. For SDSS only one repair is permitted at the same welded area.

NOTE: For pressure containing equipment and piping, see items 11.9 and 12.11 of IOGP S-705.

5.4.11 Inspection

Before welding, all base materials shall be checked for chemical composition (100% PMI testing).

Before welding, all base materials shall be checked for ferrite-austenite ratio (100% ferrite testing), as follows:

a) Ferrite testing shall be performed at least in three (3) different locations in the bevel surroundings (to check the metallurgical sanity of the materials).

b) For forgings and casting materials (such as valve bodies, flanges, etc.), ferrite testing shall be performed in at least six (6) different locations (to evaluate the solubilization heat treatment effectiveness). For forgings, the ferrite testing shall be carried out in the locations of greatest fiber elongation (deformation).

Production welds, including base materials and weld metal, shall be checked for chemical composition (100% PMI testing).

Production welds shall be checked for hardness according to requirements and acceptance criteria of Annex A of this technical specification.

Production welds shall be checked for ferrite-austenite ratio (100% ferrite testing). Acceptance criteria for ferrite testing shall be as stated in IOGP S-705/API RP 582, as follows:

a) 30% to 65% for weld metal

b) 40% to 65% for HAZ

c) 40% to 60% for base metal (including forgings and castings)

NOTE 1: Ferrite measuring instruments usually return values in the form of Ferrite Number (FN). Acceptance criteria stated above are in the form of Ferrite Content (% in volume). The reading values shall be converted in order to check the acceptance.

NOTE 2: Ferrite measuring instruments are usually able to convert from FN to Ferrite Content (%). When this conversion is not available the following relations may be used:

a) Ferrite % = 0.70 FN for DSS

b) Ferrite % = 0.65 FN for SDSS

5.5 NICKEL STEEL

5.5.1 Introduction

This item establishes the requirements for welding nickel steels (C-Ni steels) with nickel content up to 9%, which are usually employed for cryogenic applications (temperatures of -46 ºC and lower).

Since the C-Ni steels have enough carbon and hardenability to be susceptible to hydrogen-induced cracking, they must be welded with low-hydrogen consumables and processes. Preheating of 200 to 300 °F (100 to 150 °C) is helpful in avoiding hydrogen or restraint cracking.

The HAZ of 9% nickel steel will become essentially martensitic, tempered in some parts by the multiple passes. At the low carbon level characteristic of these steels, the martensite retains a high degree of toughness and post weld heat treatment is usually not necessary.

Nickel steels with nickel content in excess of 1%, when in sour service, shall always be qualified by a Sulfide Stress Corrosion test (laboratory testing) in accordance with ISO 15156-1. This test is applicable for the base materials and for the welding procedures.

5.5.2 Weldability

Nickel steels have good weldability; however, the larger the addition of nickel the higher the hardenability of steel, particularly in steels with high nickel content (Ni ≥ 5%) in which the HAZ consists of martensite with relative toughness as a function of nickel content and strict control of carbon content.

Mechanical properties and toughness may be compromised when there is overgrowth of grains of HAZ due to high heat input.

In homogeneous and, specially, heterogeneous welding, the weld pool of C-Ni steels presents low fluidity when compared to C-Mn steel.

Contaminants of foreign origin shall not contact these materials, especially the sulfur from thermal pencil, grease, soap, and so on. C-Ni steels are classified as P-Number 9 and 11A, according to ASME BPVC Section IX.

Porosity may be avoided by controlling the diffusible hydrogen and by using a very short arc.

Due to the metallurgical properties, this material presents higher capacity of magnetization, compared to carbon steel. Extra care shall be taken during the weld procedures, especially in the root welding. Demagnetization or cancellation of the magnetic field in some cases may be required before welding to prevent magnetic arc blow, especially in small diameter tubes and connections.

5.5.3 Welding Technique

The welding shall be by multiple passes, with straight and slightly convex passes. Passes that have excessive convexity shall be repaired by grinding to avoid lack of fusion. In fillet welds (e.g. socket welds) the finishing passes shall be concave.

The heat input shall be below 2 kJ/mm in homogeneous and 1.5 kJ/mm in heterogeneous welding.

For SAW process, heat input shall be lower than 2.8 kJ/mm in homogeneous and 2.5 kJ/mm heterogeneous welding, except for 9% nickel steel, heat input shall always be limited to 2.0 kJ/mm.

The manual heating by oxyfuel flame (shower-type blowtorch) shall be limited to pieces with thickness below 13 mm and a nominal diameter of up to 10 inches.

5.5.4 Welding Processes

Permitted welding processes shall be in accordance with item 4.5 of this technical specification with the following restrictions and notes.

For root pass and second pass welding, up to 6.4 mm of weld metal thickness, only GTAW process is permitted.

5.5.4.1 SMAW

a) The use of synthetic consumables is not permitted.
b) Root pass welding by SMAW process is not permitted.
c) The oscillation of the electrode shall be such that the pass width does not exceed three times the coated electrode core diameter.

5.5.4.2 GTAW

a) The purge gas shall be argon, helium, or argon + helium mixture. Purging with nitrogen is not allowed.
b) The purging of the root shall be kept until the 3rd weld layer or 8 mm, whichever is thicker.

5.5.4.3 GMAW

a) GMAW with conventional short-circuit transfer mode and globular transfer mode is not permitted.

b) Additional care shall be taken for overhead position using solid wires due low wettability of the filler metal ENiCrMo-3.

c) Root pass and second pass welding by GMAW process are not permitted. It is also not permitted to weld branch connections, nozzles to equipment's shell welds, and socket welds.

5.5.4.4 FCAW

a) The use of filler metal with specification/classification different from that one applied in the welding procedure qualification is not permitted.

b) The use of filler metal with brand name different from that one applied in the welding procedure qualification is not permitted.

5.5.4.5 SAW

a) The use of welding flux with brand name different from that one applied in the welding procedure qualification is not permitted.

b) The flux shall be neutral or basic, it is not permitted the presence of alloying elements.

c) Special care shall be given to the flux regarding the contamination risk by dirt and moisture.

5.5.5 Welding Consumables

Welding consumables shall be in according with Table 5.

Table 5 – Welding Consumables for Welding C-Ni Steels

Base Material	SMAW (AWS A5.5/A5.11)		GTAW / GMAW (AWS A5.14/A5.28)		FCAW (AWS A5.29/A5.34)		SAW (AWS A5.14/A5.23)	
	1st option	2nd option	1st option	2nd option	1st option	2nd option	1st option	2nd option
1.5% Ni	E801X-C1	-	ER80S-Ni2	-	E8XTX-Ni2	-	EBNi2	-
2.25% Ni	E801X-C1	E801X-C2	ER80S-Ni2	-	E8XTX-Ni2	-	EBNi2	-
3.5% Ni	E801X-C2	ENiCrMo-3 ENiCrFe-2 ENiCrFe-3	ER80S-Ni3	ERNiCr-3	ENiCrMo3T	-	EBNi3	ERNiCr-3
9% Ni	ENiCrMo-3	-	ERNiCrMo-3	-	ENiCrMo3T	-	ERNiCrMo-3	-

5.5.6 Preheating and Interpass Temperature

Preheating and interpass temperature limits shall be in accordance with Table 6.

Table 6 – Preheating and Interpass Temperature for C-Ni Steels

Base Material	Thickness	Preheating (minimum)	Interpass (maximum)
1.5% Ni	≤ 19 mm and C ≤ 0,2%	100 °C	250 °C
	> 19 mm or C > 0,2%	100 °C	
2.25% Ni	≤ 12 mm and C ≤ 0,2%	100 °C	250 °C
	> 12 mm or C > 0,2%	150 °C	
3.5% Ni	≤ 10 mm and C ≤ 0,2%	100 °C	230 °C
	> 10 mm or C > 0,2%	150 °C	
9% Ni	Preheating is not normally required up to thickness of 50 mm		150 °C

5.5.7 Post-Heating

It is not required, unless for thicknesses over 50 mm. In this case, post-heating at 150 °C by 1 minute per mm of thickness is recommended.

5.5.8 Post Weld Heat Treatment

PWHT may be required for welds with high thickness. It shall be performed as required by the design code.

In quenched and tempered materials, the PWHT temperature shall be 30°C lower than the tempering temperature of the base material.

5.5.9 Weld Repair

The same welded area shall not be repaired more than two times.

All weld repairs shall be performed using a specific qualified welding repair procedure, showing that the additional thermal cycle does not affect the toughness and the results in the SSC tests of the joint (the later when sour service is applicable).

The repair shall be performed using multiple passes, looking for the tempering of previous passes, regardless of if the part will be subject to PWHT. The welding shall always look for the tempering of the coarse grain region of previous passes and HAZ.

5.5.10 Additional Requirements for 3.5% Nickel Steel

5.5.10.1 Base Materials

The chemical composition of base materials shall meet the standard requirements, except for the elements given in Table 7, where more stringent contents are indicated.

Table 7 – Chemical Composition for 3.5% Nickel Steel (maximum)

Base Material	C	Mn	P	S	Si
ASTM A203 Gr. D	0.10% (1)	0.70%	0.010%	0.005%	0.25%
ASTM A333 Gr. 3					
ASTM A350 Gr. LF3					
ASTM A420 Gr. WPL3					
ASTM A765 Gr. III					
Note 1: Recommended 0.07% of carbon content based os successful testing on previous projects.					

5.5.10.2 Welding Technique

The welding procedure qualification shall be according to design codes (usually ASME), and the requirements herein listed.

Nickel steels alloys shows a relatively adherent oxide layer which shall be removed before the start of welding.

During welding procedure qualification heat input shall be controlled up to a maximum heat input of 2.0 kJ/mm. SAW welding heat input shall be limited to 2.5 kJ/mm.

In production welds the heat input shall not exceed the range approved on the qualified welding procedure, therefore the heat input shall be monitored during production welding.

Additional care shall be taken for cleaning and preparation of the joint to be welded so as to avoid the presence of contaminants. Slag shall be completely removed during and after welding.

In order to prevent high hardness at the HAZ, it is recommended to finish the welding pass in the center of the groove, grinding the corners of bead.

5.5.10.3 Impact Testing

The impact tests (Charpy V-notch) shall meet the energy requirements of the applicable standards. Test temperature shall be -100 °C.

For welding procedure qualification impact tests shall include all welding processes, and the heat affected zone.

5.5.10.4 Hardness Testing

Hardness control is mandatory in welding qualification and production welding joints.

Where sour service is applicable, during weld procedure qualification the hardness control must be done in according to ISO 15156-2 (hardness surveys for welding procedure qualification). Each qualified WPS shall then have a respective hardness limit, which has to be confirmed by a successful SSC test.

5.5.10.5 Post Weld Heat Treatment

Post weld heat treatment shall always be performed on welding procedure qualification and on production welds. PWHT parameters shall be as prescribed in the design code.

Welding procedure qualification shall always include two PWHT conditions, as follows:

a) Minimum PWHT soak time, as predicted in the design code.

b) Maximum PWHT soak time, equivalent to at least twice the soak time predicted in the design code.

Mechanical tests, including hardness, shall be performed on both conditions (minimum and maximum PWHT soak time). Where sour service is applicable, the SSC test shall be performed on the piece with the higher HAZ hardness.

5.5.10.6 Inspection

When the weld root of the production welds is inaccessible, the hardness shall be measured externally in HAZ and set as the maximum hardness found of qualified welding joint plus 5%.

Hardness shall be performed on 100% of the production welds (at least one per weld) where sour service is applicable. Hardness acceptance criteria where there in no sour service shall be as per the design code.

Hardness acceptance criteria (maximum value) where there is sour service shall be the hardness value from the supporting PQR.

5.5.11 Additional Requirements for 9% Nickel Steel

5.5.11.1 Base Materials

The chemical composition of base materials shall meet the standard requirements, except for the elements given in Table 8, where more stringent contents are indicated.

Table 8 – Chemical Composition for 9% Nickel Steel (maximum)

Base Material	C	Mn	P	S	Si
ASTM A333 Gr. 8	0.10%	0.65%	0.020%	0.005%	0.28%
ASTM A420 Gr. WPL8					
ASTM A522 Type I					

Best results regarding toughness and SSC tests are obtained using base material with chemical composition values given in Table 9. **[Recommended Practice]**

Table 9 – Chemical Composition for 9% Nickel Steel (maximum)

Base Material	C	Mn	P	S	Si
ASTM A333 Gr. 8	0.06%	0.59%	0.005%	0.001%	0.25%
ASTM A420 Gr. WPL8					
ASTM A522 Type I					

5.5.11.2 Welding Technique

The welding procedure qualification shall be according to design codes (usually ASME), and the requirements herein listed.

Nickel steels alloys and especially those with high nickel content, such as 9% nickel steel, shows a relatively adherent oxide layer which shall be removed before the start of welding. Heat input shall be controlled up to a maximum heat input of 2.0 kJ/mm.

In production welds the heat input shall not exceed the range approved on the qualified welding procedure, therefore the heat input shall be monitored during production welding.

Additional care shall be taken for cleaning and preparation of the joint to be welded so as to avoid the presence of contaminants. Slag shall be completely removed during and after welding.

In order to prevent high hardness at the HAZ, it is recommended to finish the welding pass in the center of the groove, grinding the corners of bead.

5.5.11.3 Impact Testing

The impact tests (Charpy V-notch) shall meet the requirements of the applicable standards, including the minimum temperature (-196 °C) and impact tests on weld metal and heat affected zone for welded joints.

5.5.11.4 Hardness Testing

Hardness control is mandatory in welding qualification and production welding joints.

Where sour service is applicable, during weld procedure qualification the hardness control must be done in according to ISO 15156-2 (hardness surveys for welding procedure qualification). Each qualified WPS shall then have a respective hardness limit, which has to be confirmed by a successful SSC test.

5.5.11.5 Inspection

When the weld root of the production welds is inaccessible, the hardness shall be measured externally in HAZ and set as the maximum hardness found of qualified welding joint plus 5%.

5.6 COPPER AND COPPER ALLOYS

5.6.1 Introduction

For the purpose of this technical specification, besides the commercially pure copper (99.3% Cu), the Copper-Nickel (Cu-Ni with up to 30% Ni) and Copper-Aluminum (Bronze-Aluminum up to 8% Al) alloys are considered, with the following specifications:

a) C-10200 deoxidized commercially pure copper (Cu)

b) C-70600 alloy 90Cu-10Ni (Cu-Ni-Fe)

c) C-71500 alloy 70Cu-30Ni (Cu-Ni-Fe)

d) C-61400 bronze-aluminum alloy (Al-Cu-Fe)

5.6.2 Weldability

In general, they have rapid cooling rate, favoring the lack of fusion due to the high coefficient of thermal conductivity of copper.

The weld pool of commercially pure copper has great fluidity.

Copper alloys when enriched in solute atoms become susceptible to hot cracking, which may be avoided by reduction of root opening, enhanced deposition, and by preheating in some alloys.

The mechanical properties may be compromised by the quick formation of copper oxide. This oxide is hygroscopic and highly reactive when exposed to oxygen at high temperature. The mechanical strength is compromised by the formation of pores (oxides) and impurities (antimony, arsenic, bismuth, and lead).

5.6.3 Welding Technique

Hygroscopic oxide removal, slag removal, cleaning and cutting tools shall be used exclusively for these materials, and meet the following requirements:

a) Slag removal and cleaning tools shall be made of copper alloy, stainless steel or be coated with this material, and only be used for welding of copper and its alloys.

b) The cutting discs shall have nylon core or fiberglass.

c) Additional care shall be taken as cleaning and preparation of the joint to be welded, in order to prevent the existence of contaminants.

The surface of the parts shall be protected against spatter adhesion and other projections resulting from welding.

In a range of 200 mm centered on the joint, by its internal and external sides, the joint shall be cleaned with solvent, and there shall not be any contamination with substances containing sulfur, lead, zinc, and their compounds. Thermal pencil and industrial marker shall not be used due to the risk of contamination. The welded joints shall not be contaminated by residues of any kind resulting from the welding and assembly work.

Slag shall be completely removed during and after welding. The surface irregularities of the weld shall be removed by grinding, for each deposited layer.

The welding by GTAW and GMAW processes shall be performed with back purging to protect the weld zone and HAZ. The measurement by oximeter shall indicate oxygen content of 500 ppm or lower before the start of welding.

Welds in copper alloys that will be subject to corrosive fluids (such as aerated sea water) shall always be pickled and passivated after welding to remove all heat tint.

Bevel angles for the joint preparation in Cu-Ni-Fe alloy welding are usually wider than those used in carbon steel welds since the molten pool is less fluid.

5.6.4 Welding Processes

Permitted welding processes shall be in accordance with item 4.5 of this technical specification with the following restrictions and notes.

The use of FCAW process is not permitted.

5.6.4.1 SMAW

a) Shall not be used in pressure containing equipment and piping. It can be used in low responsibility joints.

5.6.4.2 GTAW

a) Autogenous welding is not permitted.
b) In welding of deoxidized pure copper in butt joints, it may be necessary to use backing due to its high fluidity.
c) Shielding gases shall be argon, helium, or helium + argon mixture. The use of the argon results in low penetration, which may be partially compensated by increasing the preheating temperature.
d) Back purging with inert gas is required during welding in order to prevent internal oxidation on the root face and HAZ.

5.6.4.3 GMAW

a) GMAW with conventional short-circuit transfer mode and globular transfer mode is not permitted.
b) The process is more sensitive to pores formation than GTAW.
c) Argon and inert gas mixtures shall be used.
d) In welding of deoxidized pure copper in butt joints, it may be necessary to use backing due to its high fluidity.
e) The butt welding is basically performed in a flat position with spray transfer mode. Out of position, the welding may be performed in lower fluidity alloys (Cu-Ni and bronze aluminum) and using small diameter wires.

f) Back purging with inert gas is required during welding in order to prevent internal oxidation on the root face and HAZ.

5.6.5 Welding Consumables

Welding consumables shall be in according with Table 10.

Table 10 – Rods for Copper and Copper Alloys

Base Material	GTAW / GMAW (AWS A5.7)
C-10200 (Pure Cu)	ERCu
C-70600 (90Cu-10Ni)	ERCuNi
C-71500 (70Cu-30Ni)	ERCuNi
C-61400 (Al-Cu-Fe)	ERCuAL-A2

5.6.6 Preheating and Interpass Temperature

Preheating and interpass temperature shall be in according with Table 11.

Table 11 – Preheating and Interpass Temperature for Copper and Copper Alloys

Base Material	Thickness (t)	Preheating (minimum)	Interpass (maximum)
Pure Cu	t ≤ 3 mm	-	-
	3 < t ≤ 6 mm	100 °C	-
	6 < t ≤ 10 mm	220 °C	-
	t ≥ 10 mm	260 ºC to 480 ºC	-
Cu-Ni	Any	-	100 ºC
Al-Cu-Fe	t ≤ 6 mm	-	-
	t > 6 mm and Al < 10%	-	150 ºC

5.6.7 Post-Heating

Post-heating is not required.

5.6.8 Post Weld Heat Treatment

PWHT is not required.

5.6.9 Weld Repair

The same welded area shall not be repaired more than two times.

5.7 NICKEL ALLOYS

5.7.1 Introduction

The requirements herein stated applies to pure níquel and niquel-base alloys hardned by solid solution, such as: UNS N02200, N04400, N06600, N06625, N08800, N08810, N08811, N08825, N06022, N10276.

5.7.2 Welding Technique

Basic problems of welding nickel alloys may be avoided by cleaning the bevels and rods with non-chlorinated solvents, protecting them against wind and moisture, using specific tooling support for nickel alloys, and having functional hygiene with the use of gloves and apron at work.

Lack of penetration or fusion is controlled by the slight increase in bevel angle, reduction in nose height, and increase in root opening. The previous training of welders, cleaning, and removal of adhering oxide layer are essential.

Carbon arc cutting and gouging and oxyfuel cutting is not permitted.

For thermal cutting processes (e.g. plasma and laser cutting), the HAZ shall be removed by machining or grinding.

The welding shall be performed with low heat input. The input to processes with high density of current shall not exceed 1.8 kJ/mm. For SMAW and GTAW processes, it shall be lower than 1.5 kJ/mm.

The welding of nickel allows shall be performed with straight passes. To reduce the risk of solidification cracking, some details of extreme importance shall not be overlooked, such as: joint preparation, superficial cleaning, quantity of material deposited per pass in the width/depth ratio equal to one, slight convexity of passes, and suitable welding speed in order to avoid weld pool in drop form.

The risk of crater-type cracks may be mitigated by training welders in the torch outlet. The profile shall be slightly convex.

Imperfections such as dents, bites, arc strikes, and spatters shall be carefully removed. Slag removal, cleaning and cutting tools shall be compatible with nickel alloys and used only for these materials, not having iron compounds and sulfur (e.g. iron sulfide).

The part of the auxiliary assembly device touching or welded into the equipment shall have the same P-Number of the base metal, according to the classification of ASME BPVC Section IX, or otherwise be coated with the consumable specified for the welding of base metal in deposits of at least two layers. Contamination with carbon (carburizing followed by precipitation), iron and iron oxide are detrimental to corrosion resistance. The use of wedges, and copper and steel hammers or lead pads is not permitted. Contact with industrial scaffold causes exposure to zinc.

Contamination with free iron free iron or ferrous oxides may be investigated as stated in Annex G.

In case of contamination, the surface shall be cleaned by grinding or pickled by controlled etching, and then passivated. Etching and passivation shall comply with ASTM A380.

Contamination by contact with sulfur, zinc, copper, tin and lead irreversibly compromise the nickel alloys when exposed to high temperature. The use of temperature indicating sticks (crayons) based on polymer fusion and industrial markers with these contaminants is not permitted. Cutting oil shall be free of sulfur. Information about detrimental material for nickel alloys is presented on Annex H of this technical specification.

After the welding completion and before the start of operation, soaps and detergents used in bubble and liquid penetrant tests shall be removed, since they may contain elements with low melting point, especially sulfur. Slag and flux residues shall be removed after welding because they compromise the corrosion resistance in operation (fluoride). Contact with chlorine or fluoride is extremely harmful, causing stress or pitting corrosion.

Welding shall be performed with oxygen-free shielding gas at the root of weld (less than 500 ppm of oxygen) in order to protect the weld zone and HAZ. This protection shall be maintained until the completion of the third weld layer or 8 mm, ensuring the absence of oxygen. This internal protection is applicable for butt welds, socket welds, sealing welds as well as for any weld performed on the opposite side when thickness of the base material is below 8 mm (e.g. the welding of an external support in a piping requires internal gas protection). Argon and helium may be used as purge gas. Nitrogen shall only be permitted after previous evaluation and approval from BUYER. The measurement of residual oxygen shall be performed using an oximeter with threshold value of 50 ppm.

5.7.3 Welding Processes

Permitted welding processes shall be in accordance with item 4.5 of this technical specification with the following restrictions and notes.

The use of FCAW process is not permitted.

5.7.3.1 SMAW

a) The use of synthetic consumables is not permitted.

b) Root pass and second pass welding by SMAW process is not permitted.

c) Slag shall be completely removed before the joint gets into operation.

5.7.3.2 GTAW

a) Consumables shall be constantly cleaned with acetone before the opening the arc.

b) Shielding and purge gases shall be pure argon (99.99%), pure helium, or argon + helium mixture.

c) It is recommended to use tungsten electrodes with addition of Cerium or Lanthanum.

5.7.3.3 GMAW

a) GMAW with conventional short-circuit transfer mode and globular transfer mode is not permitted.

b) Root pass and second pass welding by GMAW process are not permitted.

c) The use of GMAW process for welding pressure containing equipment and piping shall have previous approval from BUYER.

d) Shielding and purge gases shall be pure argon, argon + O2 mixture (2% maximum), argon + CO2 mixture (2% maximum). Pure CO2 is not permitted.

e) The limitations of using GMAW process are due to increased susceptibility to lack of fusion, low wettability, and fluidity of nickel alloys.

5.7.3.4 SAW

a) The use of welding flux with brand name different from that one applied in the welding procedure qualification is not permitted.

b) The flux shall be neutral or basic. Alloyed fluxes are not permitted.

c) Slag and flux residues shall be completely removed before exposure of the joint in operation.

5.7.4 Welding Consumables

The consumables shall follow the instructions in Table 12.

Table 12 – Consumables for Nickel Alloys

Base Material	SMAW (AWS A5.11)	GTAW / GMAW / SAW (AWS A5.14)
Inconel 625 (UNS N06625)	ENiCrMo3 (1)	ERNiCrMo3 (1)
Note 1: Limited to operation temperature of 540 °C. Note 2: For other nickel alloys, Annex B of IOGP S-705/API RP 582 may be used as guide for consumables selection.		

5.7.5 Preheating and Interpass Temperature

Preheating is not required.

The interpass temperature shall be below 175 °C.

5.7.6 Post-Heating

Post-heating is not required.

5.7.7 Post Weld Heat Treatment

PWHT is usually not required. However, it may be required depending on the fluid and according to design specification.

5.7.8 Weld Repair

Only one repair in the same area is permitted.

The welding shall be performed with low heat input using the GTAW process.

5.8 WELD OVERLAY AND CLAD RESTORATION

5.8.1 Introduction

This section presents the welding requirements to perform weld overlay and clad restoration (usually application of Austenitic Stainless Steels and Nickel Alloys as CRA) on a less noble base material (usually carbon steel).

The requirements of item 12.3 and Annex B of IOGP S-705/API RP 582 shall be met.

The other requirements of this technical specification for the specific material shall be followed for both, base material, and clad/weld overlay material.

The minimum thickness of the weld overlay shall be 3 mm, after any grinding or machining, and shall be deposited with a minimum of two layers.

The minimum overlap in between weld passes shall be 50% or 3 mm, whichever is lower.

Weld overlay procedures shall be qualified according to design code and the additional requirements of Annex E. Any PWHT shall be performed as required by the applicable design code or service/fabrication standard for the base material.

5.8.2 Welding Processes

Permitted welding processes shall be in accordance with item 4.5 of this technical specification with the following restrictions and notes.

GTAW-Hot Wire process is also permitted.

FCAW is not recommended for welding corrosion resistant weld overlay.

5.8.3 Welding Consumables

Consumables for weld overlay of carbon steel base materials shall be according to Table 13.

Table 13 – Consumables for Weld Overlay of Carbon Steels Base Material

Overlay Material	Equipment/Piping Requiring PWHT		Equipment/Piping Not Requiring PWHT	
	First Layer	Top Layer(s)	First Layer	Top Layer(s)
316L	E/ER309LMo	E/ER316L	E/ER309LMo	E/ER316L
Inconel 625	E/ERNiCrMo-3	E/ERNiCrMo-3	E/ERNiCrMo-3	E/ERNiCrMo-3
Note: Consumables for other overlay materials shall be according to IOGP S-705/API RP 582 Table B.1.				

AISI 3XX Series weld overlays shall present the chemical composition according to Table B.2 of IOGP S-705/API RP 582.

Inconel weld overlays shall have a maximum iron (Fe) content of 10%.

5.8.4 Butt Welds in Overlaid Equipment or Piping

Butt welds of overlaid equipment shall be welded with consumables matching the base material (same chemical composition) and with subsequent internal weld overlay/clad restoration.

Butt welds of overlaid piping shall be welded with the same consumables used for the weld overlay or Inconel weld consumable (heterogeneous welding), provided that the mechanical strength of the base material is met.

For butt welds of overlaid piping (pipe to pipe or pipe to fittings welds), the following is recommended:

a) GTAW process for root pass and second pass.
b) SMAW process for filling/finishing pass.
c) In order to reduce the Fe content in the root pass, buttering may be applied on the bevels using GTAW process. **[Recommend Practice]**

The welding procedures for heterogeneous butt welds of cladded or weld overlaid material shall be qualified using cladded or overlaid materials matching the chemical composition of the production welds. Chemical analysis shall be measured on the root pass.

5.8.5 Pipe End Finish

Pipe ends shall be supplied beveled with weld overlay cladding continuous up to the pipe end.

Pipe ends shall be beveled after weld overlay cladding of internal pipe bore to avoid shrinkage effects and maintain dimensions.

Pipes ends shall be beveled by machining after any buttering applied to the original pipe bevel.

When tapering for thickness transition is required, any removal of the weld overlay shall not affects the minimum required weld overlay thickness (Figure 5). The minimum thickness of 3 mm shall be kept. If necessary, buttering shall be applied for weld overlay thickness restoration (Figure 6).

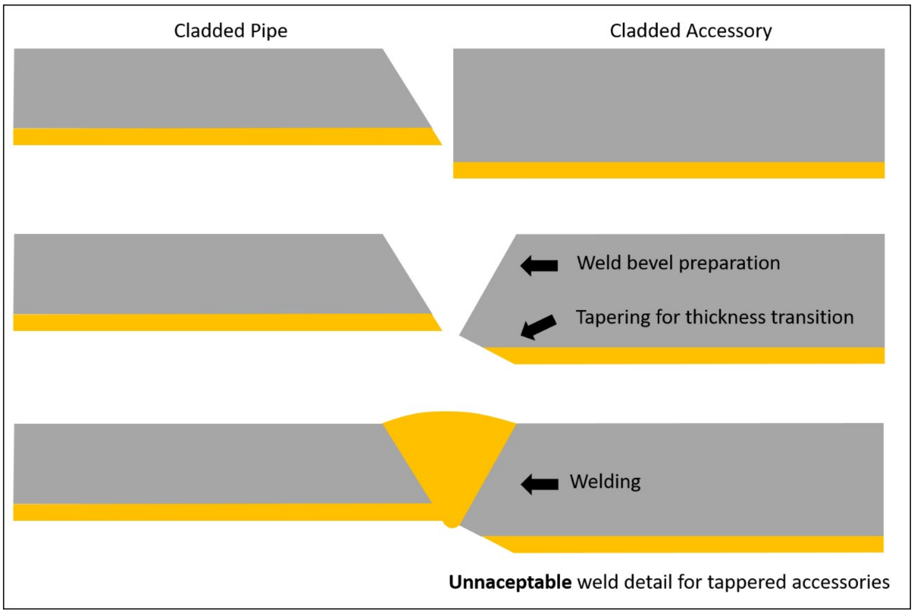


Figure 5 – Unacceptable thickness transition for overlaid piping

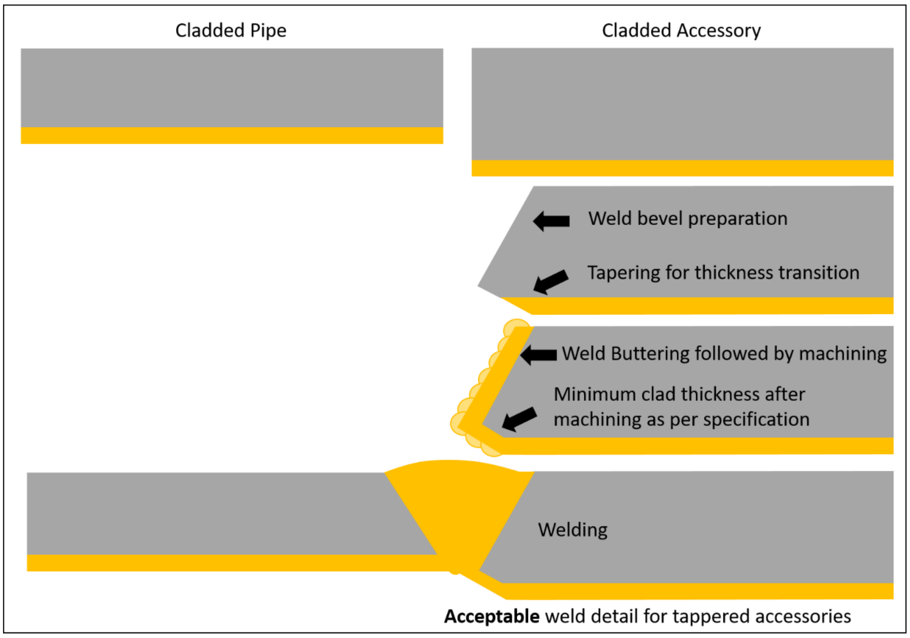


Figure 6 – Acceptable thickness transition for overlaid piping

5.8.6 Set-on Branch Connection on Piping

When performing set-on branch connections on overlaid pieces the following sequence shall be followed:

a) The carbon steel material shall be drilled on the installation point. The drilling diameter shall be at least 6 mm bigger than the internal diameter of the bore of the branch connection (Figure 7).

b) The drilled bore shall be widened in an angle suitable for welding.

c) The opened hole shall than be filled by welding with a qualified welding procedure. The chemical composition of the deposited weld metal shall be equivalent to the internal clad/overlay (Figure 8).

d) After welding the external surface shall be ground flush, and the hole for the branch connection shall be drilled again, this time with the applicable internal diameter (Figure 9).

e) All machined and drilled surfaces shall be 100% checked by PT.

f) The branch connection shall be adjusted over the machined area, and the welding performed as determined by the engineering design (Figure 10).

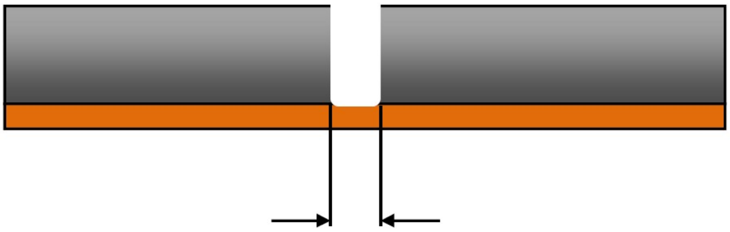


Figure 7 – Drilled bore prior to widening and welding, internal diameter 6 mm bigger than bore of the branch connection

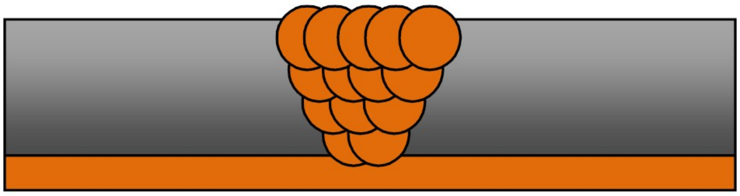


Figure 8 – Opened hole filled by welding, chemical composition equivalent to internal clad/overlay

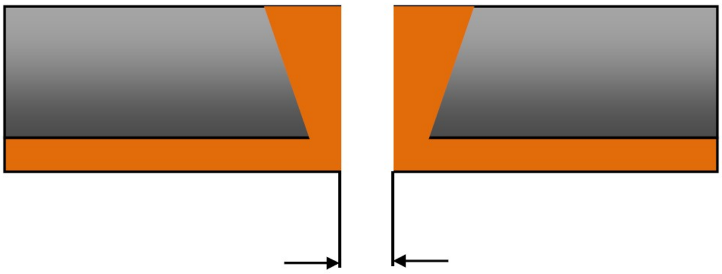


Figure 9 – External surface machined and bore reopened, this time with the correct internal diameter

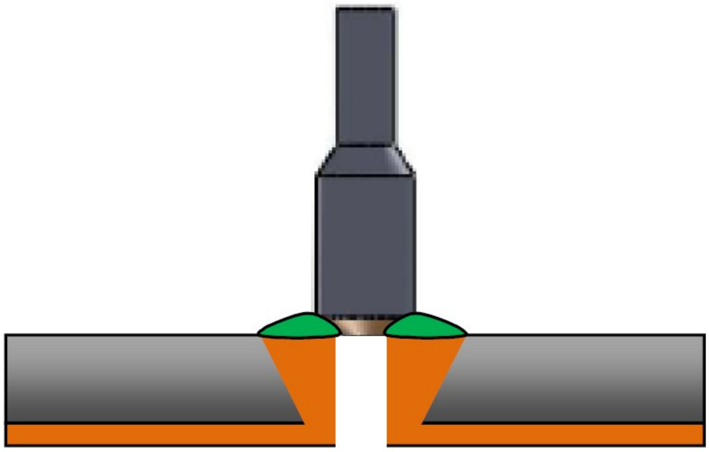


Figure 10 – Set on branch connection adjusted and welded as determined by the engineering design

5.8.7 Preparation and Blasting of Carbon Steel Base Material

Before applying the weld overlay, blasting with carbon steel shot or grit shall be performed on the internal surfaces of carbon steel pipe or equipment to remove loose rust, scale, or varnish. Grinding can also be applied as long as it does not result in the thickness reduction.

After preparation, clean and dry internally all carbon steel pipes shall be performed using dry air.

Visual inspection for cleanliness shall be as per:

a) SSPC-SP 10 or ISO 8501-1 Sa 2½ minimum when applied blasting.

b) SSPC-SP 11 when applied mechanical cleaning (by tools, e.g. grinding).

For piping, random inspection using borescope inspection or similar shall be performed to check full length. If surface scale is visible, pipe shall be re-blasted.

5.8.8 Drying Carbon Steel Base Material

Air drying of carbon steel base material is mandatory before applying the weld overlay. The clean air used for drying shall have a dew point that is at least 4 ºC higher than the ambient air dew point measured locally.

5.8.9 Inspection

Table 14 below presents the additional NDT required for piping or equipment with internal weld overlay.

Table 14 – Additional NDT for Equipment and Piping with Weld Overlay and Clad Restoration

Location	NDT	Acceptance Criteria
Weld Overlay and Clad Restoration (from internal surface)	100% VT	See below regarding VT
	100% PT	According to Design Code
	PMI	CRA Specification and item 5.7.3
Weld Overlay and Clad Restoration (from external surface)	100% UT	See below regarding UT
Buttered Bevels (after machining)	100% PT	According to Design Code

Regarding VT on the weld overlay, it shall be performed on 100% of weld overlay surface. For non-accessible areas, VT by borescope inspection shall be used. Acceptance criteria for VT shall be as follows:

a) Cracks and other linear imperfections are not permitted.

b) Surface pores are not permitted.

c) Weld overlay surface shall have a smooth appearance and be continuous without interruption. Average peak to trough height between adjacent beads less than 1 mm, except for overlapping areas (start-stop, and so on).

d) No gaps of any width between the weld beads are permitted. Overlapping weld beads with locally increased deposit thickness are allowed provided the minimum cladding thickness requirement is met and that NDT of the weld overlay is satisfactory.

Regarding PT on the weld overlay, it shall be performed on 100% of weld overlay surface. For non-accessible areas, ferroxyl test (as stated below) shall be performed and appraised by borescope inspection to verify that the cladding is continuous and base material is not exposed.

Regarding PMI on the weld overlay and clad restoration, shall be performed on 100% of the overlaid pieces.

Regarding UT examination, the procedure and acceptance criteria shall comply with Supplementary Requirement S9 of ASTM A578 standard for scanning from external surface. If scanning from the weld overlay surface, the use of ISO 17405 standard is recommended.

Defects found in the weld overlay cladding following NDT may be repaired using an approved and qualified weld procedure.

After completion of NDT, the internal clad surfaces shall be washed or otherwise cleaned to ensure that all residual traces of test materials (such as PT developer) are completely removed.

If internally washed with potable water, the pieces shall be dried by air blast using clean, dry air.

If contamination of the weld overlay or clad restoration is suspected, ferroxyl test according to Annex G shall be performed on finished overlay surfaces to check for the presence of free iron.

If copper deposits are contamination is detected, the overlay surface shall be locally pickled and passivated to remove free iron surface contamination before being re-tested and re-examined.

5.9 WELDING OF OTHER METALS AND ALLOYS

The welding of metallic materials other than the ones cited in this technical specification shall follow the applicable requirements of IOGP S-705/API RP 582.

The welding procedure qualification of Titanium shall be as stated in Annex F.

5.10 DISSIMILAR AND HETEROGENEOUS WELDING

Dissimilar joints and heterogeneous welds may lead to the application of different requirements than those herein listed for each specific material.

Before performing any such dissimilar or heterogeneous welding the SELLER shall submit to BUYER all the details for the need of performing such welds, along with the applicable metallurgical details and considerations. The intended supporting weld documents shall be submitted as well (PQR or the intended preliminary WPS).

The following factors, among others, shall be considered when performing dissimilar welds:

- Solubility limits
- Formation of intermetallic compounds
- Weldability
- Thermal Expansion
- Melting temperatures and rates
- Corrosion
- End-service conditions

The requirements of IOGP S-705/API RP 582 shall be met.

NOTE: Item 6.2 and Annex A of IOGP S-705/API RP 582 shall be used as a guide to select the consumables.

For welding procedure qualification of dissimilar joints between Duplex/Superduplex Stainless Steels and Carbon Steel, Annex D of this technical specification shall be followed.

This Section does not apply to weld overlay applications, which shall follow the requirements of the design/service/fabrication code and Section 5 of this technical specification.

ANNEX A – HARDNESS TESTING REQUIREMENTS

A.1 Objective

A.1.1 This Annex establishes the requirements for performance of hardness measurement test in welding procedure qualification and production tests in laboratory, and field hardness measurement of production welds.

A.1.2 This Annex does not define the evaluation of deviations regarding the hardness acceptance criteria defined by design, fabrication, construction, and assembly standards.

A.1.3 When the design, fabrication or assembly standard requires a hardness testing, the welding procedure qualification shall be complemented by this test at the weld zone, heat-affected zone, and base metal. Its results shall be consistent with the reference standard.

A.2 Welding Procedure Qualification

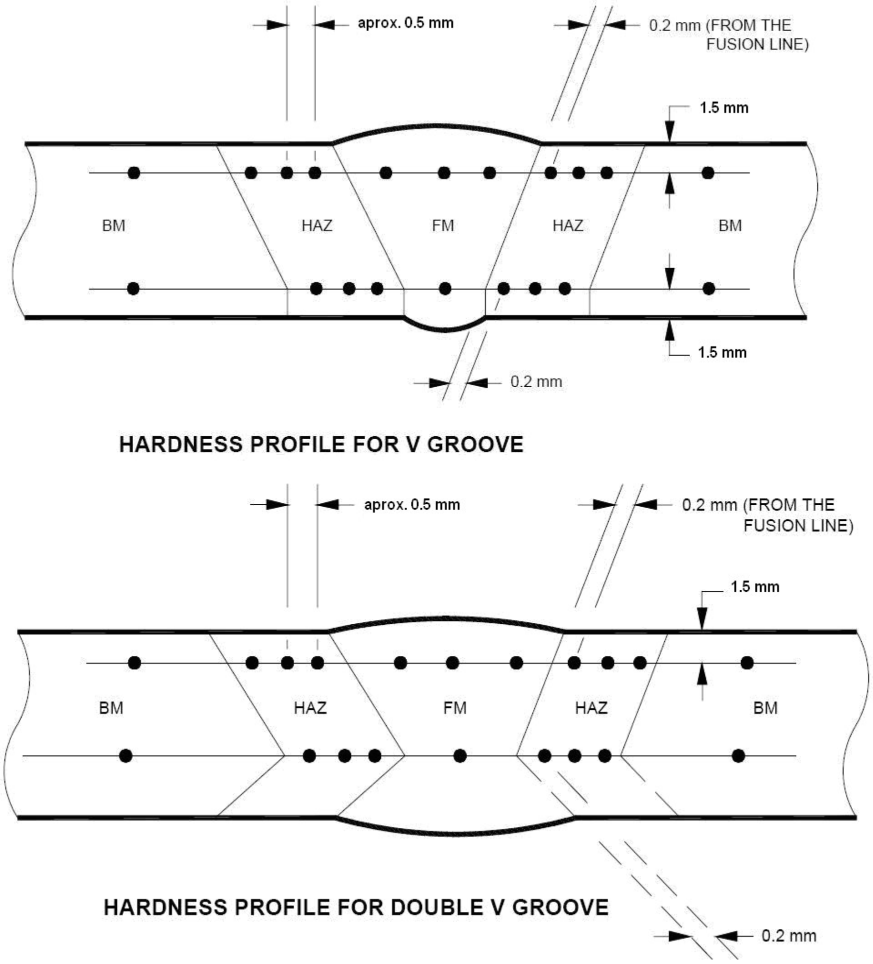
A.2.1 The welding procedure qualification shall be hardness tested by HV10 or HV5 method in accordance with ASTM E92 or ISO 6507-1. The procedure qualification test shall meet the requirements (e.g. PWHT) imposed on production joints. The hardness survey shall be performed on a transverse weld cross section that has been polished and etched to identify the weld metal, fusion line and HAZ.

A.2.2 For material in sour service applications, the hardness requirements of ISO 15156 shall also be met.

A.2.3 Unless otherwise specified in a specific standard (e.g. ISO 15156), hardness traverses shall be performed according to Figure A.1 (typical single-sided and double-sided welds). The HAZ readings shall include locations as close as possible (approximately 0.2 mm) to the weld fusion line.

A.2.4 Acceptance criteria shall be according to design code, service standard (e.g. ISO 15156) or Table 12 of IOGP S-705, the most stringent criteria shall prevail.

A.2.5 The hardness test results shall be recorded in the PQR.



Note: If necessary, intermediate readings may be slightly dislocated from the horizontal line.

Figure A.1 – Location of Vickers Hardness Indentations

A.3 Production Welds

A.3.1 The requirements here stated is regarding hardness test of pressure containing equipment and piping production welds.

A.3.2 Welds shall be hardness tested, where required, on the side contacted by the process fluid whenever possible. If access to the process fluid side is not feasible, such as on piping or small diameter vessels, hardness testing shall be done on the opposite side.

A.3.3 Testing shall be performed after any required PWHT.

A.3.4 Readings shall include weld metal, HAZ and base metal.

A.3.5 The test location and frequency shall be according to item A.4 unless otherwise specified by the applicable code/standard or as required by BUYER’s technical specifications.

A.3.6 Equipment and test procedure shall be in accordance with I-ET-3010.00-0000-970-P4X-002 – REQUIREMENTS FOR NON-DESTRUCTIVE TESTING.

A.3.7 Acceptance criteria shall be according to design code, service standard (e.g. ISO 15156) or Table 12 of IOGP S-705, the most stringent criteria shall prevail.

A.3.8 Hardness test results and locations shall be recorded.

A.4 Test Location and Frequency

A.4.1 For equipment, test location and frequency of hardness test shall be as stated in I-ET-3010.00-1200-540-P4X-001 – REQUIREMENTS FOR PRESSURE VESSELS DESIGN AND FABRICATION.

A.4.2 For piping, test location and frequency of hardness test shall be as stated in I-ET-3010.00-1200-200-P4X-115 – REQUIREMENTS FOR PIPING FABRICATION AND COMMISSIONING.

ANNEX B – WELDING REPAIR

B.1 Minor Surface Repairs

B.1.1 Minor surface imperfections or damage on welded joints may be removed by grinding provided that the remaining wall thickness at any point is not less than minimum specified wall thickness.

B.1.2 The ground area shall be carefully dressed to ensure a smooth transition with the surrounding surface, with no notches.

B.1.3 The ground area shall be MT or PT inspected to ensure that the defects have been removed.

B.2 Welding Repairs

B.2.1 Before repair welding, the defect shall be completely removed.

B.2.2 The excavated area shall have smooth transitions to the surface and allow good access for both NDT after excavation and subsequent repair welding. After excavation, complete removal of the defect shall be confirmed by MT or PT.

B.2.3 The excavated groove shall be minimum 50 mm long, measured at defect depth even if the defect itself is smaller.

B.2.4 Defects spaced less than 100 mm shall be repaired as one continuous defect.

B.2.5 Repair welding shall be performed using the same WPS as for the original weld, or a separately qualified welding repair procedure.

B.2.6 All weld-repaired areas shall be ground to a smooth contour with the base material or existing weld. Care shall be taken to ensure that over-grinding does not occur and that the minimum wall thickness is maintained.

B.2.7 After welding repair finished, the repaired area plus at least 100 mm on each end shall be subjected at least to the same NDT specified for the original weld.

B.2.8 Unless otherwise specified, welding repair may only be carried out twice in the same area.

B.2.9 If any welding repair is performed after PWHT and/or hydrostatic test, then the PWHT and/or hydrostatic test shall be repeated.

B.2.10 Any welding repair and welding repair procedure qualification shall also follow the requirements of IOGP S-705.

B.3 Re-Welding

B.3.1 Re-welding (from weld cut-out) shall include complete removal of the original weld metal and HAZ.

B.3.2 Re-welding shall be performed using the same WPS as for the original weld.

B.3.3 The re-welded joint shall be subjected at least to the same NDT as specified for the original weld.

ANNEX C – ADDITIONAL REQUIREMENTS FOR WELDING PROCEDURE QUALIFICATION OF DUPLEX/SUPERDUPLEX STAINLESS STEEL

C.1 Additional Essential Variables

C.1.1 The requirements of Section 11 and Table 11 of IOGP S-705 shall be met.

C.2 Requirements for Welding and Preparation of Test Coupons

C.2.1 Welding procedures for duplex stainless steels shall be qualified in accordance with design code and the additional requirements of IOGP S-705 (item 11.3) and this Annex.

C.2.2 The travel speed (TS) and heat input (HI) shall be recorded in the PQR.

C.2.3 Heat input shall be calculated by equation:

$$HI = \frac{60 \times V \times I}{1000 \times TS(mm/min)}$$

C.2.4 Run out length and arc time shall be recorded in order to determine the travel speed for each welding pass.

C.2.5 Reading shall be taken for each individual arc time even though any pass may contain two or more arc times. Suitably calibrated equipment, approved by BUYER, shall be used to monitor the welding.

C.3 NDT on Test Coupons

C.3.1 Non-Destructive Testing (NDT) shall be undertaken in the as deposited condition unless clearly stated on the pWPS. In this case the pWPS shall explicit the extent and method of weld cleaning.

C.3.2 The following NDT shall be performed for each welding procedure test coupon:

a) For butt welds: VT, PT and RT (100% for all).

b) For fillet welds: VT and PT (100% for all).

C.4 Laboratory Testing

C.4.1 The tests listed in Table C.1 shall be carried out on an DSS or SDSS welding procedure qualification, additional to the qualification standard/code.

Table C.1 – Additional tests for DSS and SDSS

Test	Extend	Procedure	Acceptance Criteria
Chemical Analysis	Weld Metal	-	According to base metal specification
Microstructural Examination	Weld Metal HAZ Base Metal	According to ISO 17781 and item C.5.1	According to ISO 17781
Ferrite Content Measurement	Weld Metal HAZ Base Metal	According to ISO 17781	30% to 65% - Weld Metal 40% to 65% - HAZ 40% to 60% - Base Metal
CVN Impact Toughness Test	Weld Metal Fusion Line Fusion Line +2 mm	According to ISO 17781 and item C.5.2	Energy values shall be according to ISO 17781 Quality Level II (QL II) Minimum lateral expansion 0.38 mm
Corrosion Test	Weld Metal HAZ Base Metal	According to ISO 17781 and item C.5.3	According to ISO 17781
Hardness Test	Weld Metal HAZ Base Metal	According to Annex A	The most stringent between ISO 15156-3 and IOGP S-705 Table 12

C.5 Notes

C.5.1 Microstructural Examination: Photographs shall be included in the report.

C.5.2 Charpy V-Notch Impact Toughness Test:

a) CVN impact test shall be performed at -46 °C or MDMT, whichever is lower.

b) One set (3 specimens) for each location.

c) Whenever possible, full-size specimens shall be applied.

d) For subsize specimens, the energy reduction factor of ISO 17781 shall be used.

e) CVN impact test is not required for wall thickness lower than 6 mm.

C.5.3 Corrosion test specimens shall be as specified herein:

a) The specimen shall be tested in the as-welded condition, without removal of the reinforcement and the root pass.

b) The test specimen shall have a dimension of full wall thickness x 25 mm along the weld x 50 mm across the weld.

ANNEX D – ADDITIONAL REQUIREMENTS FOR WELDING PROCEDURE QUALIFICATION OF DISSIMILAR JOINTS BETWEEN DUPLEX STAINLESS STEEL AND CARBON STEEL

D.1 Test Coupon

D.1.1 In addition to requirements the applicable code, impact test shall be made using a butt weld joint design to give a full thickness path for crack opening into the HAZ of carbon steel base metal.

D.1.2 Weld joints should be according to Figure D.1.

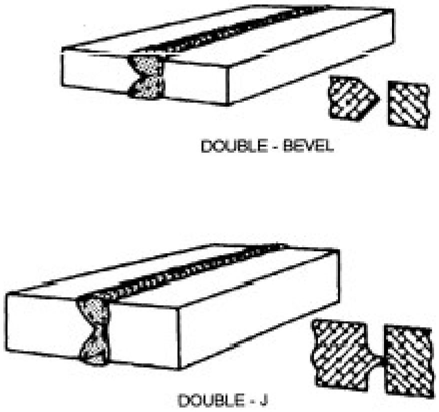


Figure D.1 – Butt Weld Joints Test Coupon

D.2 CVN Specimens

D.2.1 One set of CVN specimens shall be tested according to standard ASTM E370. The specimens shall be cut in order that the V notch goes straight through the HAZ of carbon steel base metal according to Figure D.2.

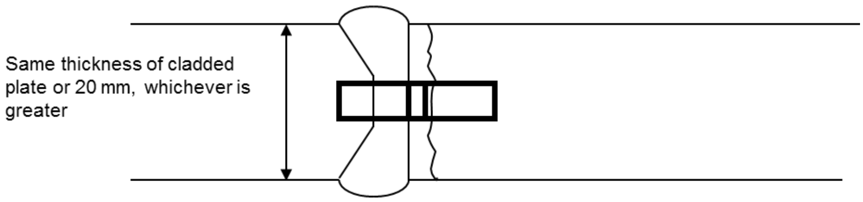


Figure D.2 – Location for removal of CVN specimens from butt weld joints

D.2.2 Acceptance criteria:

a) Average value: 27 J at -18 ºC or at MDMT, whichever is lower.

b) Single value: not below 70% of the average value required.

ANNEX E – ADDITIONAL REQUIREMENTS FOR WELDING PROCEDURE QUALIFICATION OF WELD OVERLAY

E.1 Additional Essential Variable

Decrease the number of layers shall be considered as essential variable for welding procedure qualification.

E.2 NDT and Laboratory Testing

The tests required for welding procedure qualification of weld overlay and clad restoration shall be according to Table E.1 (for AISI 3XX Series) or Table E.2 (for Inconel) below.

Table E.1 – Tests for Weld Overlay Procedure Qualification for AISI 3XX Series

Test	Extend	Acceptance Criteria
Visual Testing	100%	According to item 5.8.9
Penetrant Testing	100%	According to ASME BPVC Section IX or Design Code
Ultrasonic Testing	100%	According to item 5.8.9
Side Bend Test	4 specimens	According to ASME BPVC Section IX
Macroscopic Examination	See item E.3.1	According to item E.3.1
Microscopic Examination	See item E.3.2	Grain boundary with no continuous precipitations
Chemical Analysis	See item E.3.3	According to item 5.8.3
Ferrite Content (%) or Ferrite Number (FN)	See item E.3.4	According to item E.3.4
Hardness Testing	See item E.3.5	According to item E.3.5
Intergranular Corrosion Test (when PWHT is required)	1 specimen	According to item E.3.6

Table E.2 – Tests for Weld Overlay Procedure Qualification for Inconel

Test	Extend	Acceptance Criteria
Visual Testing	100%	According to item 5.8.9
Penetrant Testing	100%	According to ASME BPVC Section IX or Design Code
Ultrasonic Testing	100%	According to item 5.8.9
Side Bend Test	4 specimens	According to ASME BPVC Section IX
Macroscopic Examination	See item E.3.1	According to item E.3.1
Microscopic Examination	See item E.3.2	Grain boundary with no continuous precipitations

Chemical Analysis	See item E.3.3	According to item 5.8.3
Hardness Testing	See item E.3.5	According to item E.3.5

E.3 Notes

E.3.1 Macroscopic Examination: Macroscopic examination shall be performed at cross section surface of the test coupon. Cracks and other planar defects are not permitted. Individual pores or clusters of pores exceeding 2 mm are not permitted.

E.3.2 Microscopic Examination: Microscopic examination shall be performed at cross section surface of test coupon and shall include each layer and the interface between base material and weld overlay (fusion line).

E.3.3 Chemical Analysis: Chemical analysis shall be measured on a sample taken from the test coupon. Locations of chemical analysis to shall be at prepared surface and 1.5 mm below prepared surface.

E.3.4 Ferrite Content / Ferrite Number: Ferrite Number shall be measured on the top layer of weld overlay and shall be in the range of 3 to 10 FN for AISI 3XX Series, except for AISI 347 which shall have a range of 5 to 11 FN.

E.3.5 Hardness Testing: Hardness Testing shall be performed according to Annex A. The survey shall be according to Figure E.1. Readings on the HAZ shall be located as close as possible of the fusion line into the base material. A minimum of three readings shall be placed in the HAZ.

Acceptance criteria shall be according to design code, service standard (e.g. ISO 15156, if applicable) or Table 12 of IOGP S-705, the most stringent criteria shall prevail. The hardness for Inconel shall be in the range of 200 to 310 HV10.

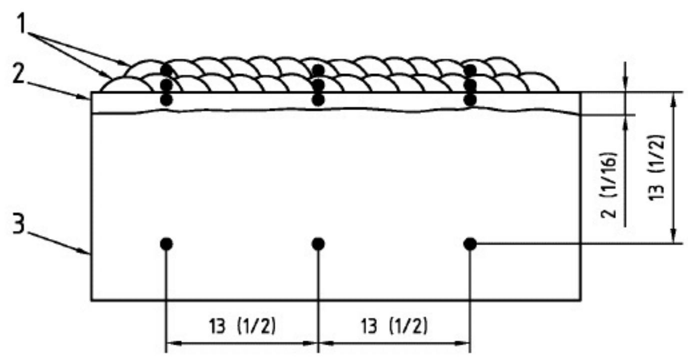


Figure E.1 – Required Hardness Test Locations, (1) Overlay, (2) HAZ, (3) Base Material

E.3.6 Intergranular Corrosion Test: When PWHT is required for base materials with AISI 3XX Series weld overlay, weld procedure qualifications shall include corrosion testing according to ASTM A262 Practice C.

ANNEX F – ADDITIONAL REQUIREMENTS FOR WELDING PROCEDURE QUALIFICATION OF TITANIUM (AND THEIR ALLOYS)

F.1 NDT and Laboratory Testing

The tests required for welding procedure qualification of titanium and their alloys shall be according to Table F.1.

Table F.1 – Examination and Testing of the Test Coupon

Test	Extend	Acceptance Criteria
Visual Testing	100%	According to design code and/or qualification standard
Penetrant Testing	100%	According to design code and/or qualification standard
Radiographic Testing	100%	According to design code and/or qualification standard
Transverse Tensile Test	2 Specimens	According to design code and/or qualification standard
Transverse Bend Test	4 Specimens	According to design code and/or qualification standard
Macro/microscopic Examination	1 Specimen	According to design code and/or qualification standard and according to ISO 15614-5
Hardness Testing	Weld Metal, HAZ, and Base Metal	According to IOGP S-705 (or ISO 15156-3 for sour service applications)

ANNEX G – PASSIVITY TEST FOR NICKEL AND NICKEL ALLOYS

G.1 Scope

This test is intended to reveal the presence of free iron or ferrous oxides on nickel alloy surfaces. Free iron contamination may exist as superficial films or as inclusions.

Two methodologies are accepted to analyze the presence of iron or ferrous oxides on nickel alloy surfaces, as follows.

G.2 Test Procedure with Demineralized Water

The surfaces to be tested shall be sprayed every hour for a period of 12 hours with cold demineralized water without intermediate drying. This period may be reduced to 6 hours if the sprayed drops are sufficiently small to adhere without running down.

A visual examination (using lens with 5x magnification in case of doubt) is performed after the surface is exposed to air for at least 24 hours after water exposure.

G.3 Test Procedure using Ferroxyl

Ferroxyl test shall be according to ASTM A380.

G.4 Acceptance Criteria

The examined surface shall have neither free iron nor iron oxide surface contamination nor iron inclusions or embedded particles.

ANNEX H – PROHIBITED AND DETRIMENTAL MATERIALS FOR NICKEL AND NICKEL ALLOYS

H.1 Prohibited Materials

Lead (Pb), mercury (Hg) and others low melting point elements, their alloys and/or their compounds shall not be added to the consumable products as essential chemical constituents.

Sulfur (S), Lead (Pb) and others low melting point elements, their alloys and/or their compounds shall be prohibited for use in fabrication, testing, shipping, and assembly.

H.2 Detrimental Materials

A detrimental element/compound is one that can have a deleterious effect on performance once it contacts the equipment. Detrimental elements/compounds are classified into seven (7) groups.

Each group has allowable maximum concentration limits of detrimental elements/compounds in contact with nickel base alloys at each step of fabrication. Possible sources of detrimental materials are indicated in Table H.1.

H.3 Controlled Products

Controlled products which contain detrimental elements/compounds in excess of the concentration limits as shown in Table H.1 may be used if at least, one of the following conditions is satisfied:

a) No transfer of detrimental elements/compounds to the parts of the equipment occurs.

b) Detrimental elements/compounds shall be removed later with another accepted product prior next fabrication steps.

c) BUYER has specifically authorized the use of the products.

H.4 Acceptable Products

Acceptable products are products listed which satisfy the detrimental elements/compounds concentrations limits of Table H.1.

Table H.1 – Acceptable Products

Detrimental Element/Compound	Concentration (maximum)	Possible Sources	Step of Fabrication
Mercury	0.5 ppm	Chemicals Instrumentation Mercury Lighting	All
Lead	0.5 ppm	Temperature crayons, hammers, cutting oils, paint, plating, wire brushes	All
Cadmium, Magnesium, Tin, Zinc, Antimony, Arsenic, Bismuth, Silver	10 ppm	Hammers, fixtures, lubricants, cutting oils, paint, plating, wire brushes	Final cleaned surfaces or any prior to or during thermal treatment
Aluminum and Copper	250 ppm	Soft pads or hammers, probes, tips, copper chill blocks and electrodes for welding	
Sulfur	100 ppm	Furnace atmosphere, marking materials, lubricants and cutting oils, UT couplants, fluxes	Final cleaned surfaces, prior to or during thermal treatment or machining
Chlorides and Halogens	200 ppm	Human perspiration, lubricants, cutting oils, fluxes, penetrant materials, lagging, UT couplants	
Phosphorous	250 ppm	Furnace atmosphere, marking materials, temperature crayons, lubricants, UT couplant	