STANDARD MATERIAL SPECIFICATIONS

CARBON STEELS FOR PRESSURE SERVICE

Application to plain carbon steel & carbon steel with clad or overlay

(IN-042.0)
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GENERAL COMMENTS

The information given hereafter for “Base Metal Quality” and “Welding” results from Axens/IFP experience in the field of refining and petrochemical industry. Carbon steel is involved for manufacturing of many equipments, components or pipe works in a wide variety of processes. Axens/IFP experience for hydrogenation of light ends or high pressure units is specifically highlighted.

The data given here are defined in the aim at giving an appropriated quality and safety level for the equipments operated under pressure. Specific codes, as well as Final User, Owner of equipment and Engineering Contractor standards may also influence the choice in materials and methods. In case of interference during the project, between the present specification and others (issued by Owner and/or Engineering Contractor) or codes, the more stringent criteria will have to be considered.

PREAMBLE

Specifications of carbon steels by Axens will be done by using two different appellations (if necessary accompanied by additional requirements):

- Carbon Steel (CS)
- Low Temperature Carbon Steel (LTCS)

When grades (and corresponding specifications) are considered in this document, the main indication is according to ASME. Indications of corresponding grades according to European Norms are put in brackets. As EN specifications are closer to “state of art” of major steel producers, they are preferred by Axens. Double certification according to both standards may sometimes be obtained.

Final grade selection shall be achieved by Owner or Engineering Contractor based on this specification and project frameworks.

Use of quenched and tempered micro-alloyed carbon steel is allowed only if specified or approved by Axens.
1. SCOPE

This specification covers the requirements for carbon steels to be used for the fabrication of pressure equipments (vessels, piping, valves, fittings, tubing,...) handling fluids containing or not hydrogen and hydrocarbons and built in accordance with the ASME Code as applicable.

For hydrogen service with operating temperature above 220°C, use of carbon steel is done according to API 941, 6th Edition, March 2004 (Nelson curves) and following the specific requirements (chemical composition and stress relieve treatment) mentioned in this document.

Additional components of streams may also induce corrosion for carbon steel:

- Some (sulfur, naphthenic acids, etc) may create uniform corrosion on carbon steel covered by this specification.

- Others (caustic, methanol, etc) may create cracking which can be avoided by using carbon steel covered by this specification provided that a suitable stress relieve treatment, usually indicated as PWHT, is applied.

- But others (wet H₂S, sour water, amines, etc) induce specific type of corrosion (SSC, HIC, SOHIC, etc) that needs additional requirements compared with present specification. These additional requirements for carbon steels in wet H₂S and sour water service are presented in Axens specification IN-043. Indication to follow this specification is noted on corresponding equipment data sheet or piping tag numbering issued by Axens.
2. DESIGN CODE (AS REFERENCE)

ASME Section VIII, Div. 1  Pressure Vessels, 2007, 2008a Addenda
ASME Section VIII, Div. 2  Pressure Vessels - Alternative rules, 2007, 2008a Addenda
ASME Section II, Part A  Ferrous Material Specifications, 2007, 2008a Addenda
ASME Section II, Part D  Properties, 2007, 2008a Addenda
3. LOW TEMPERATURE CARBON STEEL

The specification of LTCS is always linked with indication of a Minimum Design Metal Temperature (MDMT) on corresponding equipment datasheet or piping tag numbering issued by Axens. Axens considers that toughness of material at specified MDMT must be intrinsically warranted by use of materials requiring impact test at temperature lower or equal to specified MDMT. As common practice, Axens specifies LTCS (for all components) if the MDMT is lower than -5°C.

Other means as indicated by codes (curves indicating temperatures for which impact test are not required versus thickness, lower allowable minimum temperature versus reduced stress, etc) are not considered by Axens as suitable during process licensing phase. Use of such methods by Engineering Contractor or Final User is subject to formal approval from Axens who may reject them, especially if safety of process requires absence of brittleness at this MDMT and if this low MDMT is due to process conditions (opposite to atmospheric conditions).

Systematic imposition by EN of impact tests for all grades at low temperature (compared with optional requirement of ASTM) combined with higher energy value (≥27J compared to the range 14J to 27J depending on grade for ASME) and EN imposition of normalized condition lead Axens to prefer EN specifications.

In some cases, an equipment may withstand 3 sets of operating conditions:
- normal operation (approximate temperatures range 40-300°C),
- low temperature due to depressurization (less than -20°C),
- high temperature regeneration of catalyst (470°C-500°C during 1 to 2 days per year).

The material specification by Axens will be LTCS instead of LAS (1.25Cr-0.5Mo) based on following arguments:
- impossibility to obtain satisfactory Charpy V-notch tests for LAS 1.25Cr–0.5Mo leading to risk of brittle ruptures of equipment or piping at low temperature,
- kinetic rate of graphitization of LTCS at 470°C-500°C during short duration is negligible. Graphitization is evidently reduced if carbon content is low. Stability of cementite is increased as manganese content is increased, resulting in lowering of graphitization kinetic. As allowed by SA 516 specification, Mn content can be increased while C content is decreased at same mechanical characteristics. EN specifications directly allow higher Mn content.
4. EQUIPMENT MANUFACTURING

CS or LTCS must be fully killed carbon steel whichever the destination: pressure vessel, piping, structural steel welded on pressure components, internals (if made of CS or LTCS). Current conditions of production of steel are such that use of non fully killed carbon steel is prohibited by Axens for equipments or piping of his licensed units.

If for any reason a non fully killed carbon steel is selected by Engineering Contractor or Final User, one must note that such a decision would be under the responsibility of Engineering Contractor or Final User.

4.1 Base material for plates

The CS plates used for the fabrication of the equipments (vessels or welded pipes) shall comply with the basic requirements of the ASME Section II, Part A specification SA-516/SA-515 and SA-20 (or EN 10028-2 grade P235GH, P265GH, P295GH, P355GH).

When LTCS is specified, the requirements of SA-516 in normalized conditions with additional supplementary requirement S5 for Charpy V-notch impact testing shall be applied (or EN 10028-3 grade P275NL1-NL2, P355NL1-NL2).

These basic requirements are supplemented by additional requirements mentioned in following paragraphs 4.1.1 to 4.1.3. The grade is to be defined in the project framework by Engineering Contractor or Owner.

4.1.1 Steel making process

The steel plates shall be made by electric furnace vacuum degassed steel process or basic oxygen furnace process with heated ladle refining and vacuum degassing.

Preference of Axens is for plates delivered in normalized conditions. It must be noted that EN specifications impose normalization heat treatment including normalizing rolling for all grades and thicknesses. According to ASME, normalization is not always mandatory; accelerated cooling delivery conditions must be subject to Owner’s approval.

Ultrasonic Examination (UT) shall be performed in accordance with Specification A578/A578M (EN 10160) for thicknesses above 1½ inch.

4.1.2 Specific chemical requirements

Axens recommends to select CS or LTCS with Si content higher than 0.15% on product. Furthermore this requirement is in accordance with actual “state of art” of majors steels producers. Basically, this is to prevent corrosion by organic compound sulphidation at high temperature.

The following specific chemical analysis of the present steel grades is relating to the equipment operated in hot hydrogen service above 220°C. The steels shall be in conformity with EN specifications requirements for C, P and S, and with the following values on Carbon Equivalent:
-  \( \text{Ceq} < 0.42\% \) for thicknesses below 2”
-  \( \text{Ceq} < 0.45\% \) for thicknesses above or equal to 2”

With \( \text{Ceq} = C + \frac{Mn}{6} + \frac{(Cr + Mo + V)}{5} + \frac{(Ni + Cu)}{15} \)

4.1.3 Mechanical properties

4.1.3.1 Test Specimens

As per code requirements SA20 / SA370 unless otherwise specified by the project.

The Mechanical Tests shall be carried out after heat treatments simulating those anticipated along the fabrication that is post-forming heat treatment, intermediate HT, if any, and final PWHT plus additional heat treatments to anticipate potential repair (number to be defined by Contractor/Owner).

The Impact Tests shall be carried out after heat treatments simulating those anticipated along the fabrication that is post-forming heat treatment and intermediate HT, if any, and also final PWHT.

All tensile, impact testing on heat affected zones shall be carried out on samples from production weld test plates.

4.1.3.2 Tensile properties

Tensile tests shall be carried out at room temperature (Tensile tests at design temperature may eventually be requested for information, depending on the Contractor specification).

Room temperature tensile properties shall meet the requirements of the material standard.

Yield strength at design temperature shall meet the value taken into account in calculation notes (Ultimate Tensile Strength will be given for information).

**Note:**

*For Creep range calculation, Yield and Ultimate Strength may be given for information at the Owner/ Engineering Contractor discretion.*

4.1.3.3 Impact test properties

Charpy V-notch impact testing is required for all pressure retaining components. The impact test values mentioned in this document correspond to the average of absorbed energy required for three samples taken in transverse orientation and impact tested at given temperature.

If CS is specified (no indication of MDMT), impact test values shall not be less than those indicated in EN10028-2 specification: minimum 34J at 0°C.

If LTCS is specified, in accordance with code (UG84 for ASME VIII Div 1 and §3.11.2 for ASME VIII Div 2), impact tests must be done at a temperature not higher than MDMT. The impact test values shall be in accordance with code but not less than those indicated in EN10028-3 specification:
4.1.3.4 “Z” quality

The plates should have a guaranteed through thickness ductility. This guarantee is given by the “Z” parameter value which is defined by the minimum average reduction of area on 3 specimen taken in the “Z” direction. Tests specimen, subjected to anticipated heat treatment cycle, are taken through the thickness and the said reduction shall not be less than 35% of the initial cross section: this corresponds to “Z35” quality. Test could be carried out following ASTM A770.

<table>
<thead>
<tr>
<th>Test Temperature</th>
<th>-50</th>
<th>-40</th>
<th>-20</th>
<th>(°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Energy</td>
<td>P...NL1</td>
<td>27</td>
<td>35</td>
<td>(J)</td>
</tr>
<tr>
<td></td>
<td>P...NL2</td>
<td>27</td>
<td>30</td>
<td>40</td>
</tr>
</tbody>
</table>

4.1.3.5 Responsibility for Base Material Tests

Mechanical tests may be performed by the base materials Manufacturer or the vessel Manufacturer. The base materials Manufacturer shall guarantee that the minimum mechanical properties required will be met after all anticipated heat treatments of the reactor during and after fabrication.

Mill test report shall be supplied for all materials.

4.2 Base material for forgings

The CS forgings, used for nozzles or body flanges, which weight does not exceed 4540kg (10000Lb) may be supplied per ASME specification SA-105 while the others shall conform to all requirements of ASME specification SA-266 Grade 2 or 4 (or EN10222-2 grade P245GH, P280GH, P305GH).

If LTCS is specified, forgings parts requiring notch toughness testing may be supplied per ASME specification SA-350 Gr LF2 Cl 1 (or EN 10222-4 grade P285QH, P355QH).

4.2.1 Steel making process

All forgings shall be ordered from steel made by the electric furnace vacuum degassing process or basic oxygen furnace process with heated ladle refining and vacuum degassing.

Concerning the heat treatment of delivered product, the forgings shall comply with the requirements of corresponding specifications (normalized or quenched/tempered).

Forgings for fabrication of shells will preferably be made from hollow ingots.

4.2.2 Chemical analysis

The specific restrictions exposed for plates shall be applied with the following values on Carbon Equivalent:

- Ceq < 0.43% for thicknesses below 2”
- Ceq < 0.46% for thicknesses above or equal to 2”
4.2.3 Impact test properties
For CS (no indication of MDMT), if the forging is used for pressure vessel, the requirements for impact test must follow those defined for plates. In all other cases, the impact test values shall not be less than those indicated in EN10022-2 specification: minimum energy 27J at 0°C.

If LTCS is specified, impact tests must be done at a temperature not higher than MDMT. The impact test values shall be in accordance with code but not less than those indicated in EN10022-4 specification: minimum energy 27J at -20°C. To be noted that impact tests at lower temperature are possible by agreement with steel producer.

4.3 Seamless piping
CS used for seamless piping may be supplied according to ASME specification SA-106 Gr B and Gr C (or EN 10216-2+A2 grade P235GH, P265GH).

If LTCS is specified, seamless pipes requiring notch toughness testing may be supplied per ASME specification SA-333 Gr 1 and Gr 6 (or EN 10216-4 grade P215NL, P255QL, P265NL).

4.3.1 Steel making process
Concerning the heat treatment of delivered product, the seamless piping shall comply with the requirements of corresponding specifications (normalized or quenched/tempered).

4.3.2 Chemical analysis
The specific restrictions exposed for plates shall be fully applied.

4.3.3 Impact test properties
For CS, if the seamless pipe is used for pressure vessel, the requirements for impact test must follow those defined for plates. If it is used for piping, the requirements of EN 10216-2+A2 specification are applied: minimum energy 27J at 0°C.

For LTCS the impact test requirements done at a temperature not higher than MDMT, follow the corresponding code but is not less than those indicated in EN10216-4 specification:

<table>
<thead>
<tr>
<th>Test Temperature</th>
<th>-50</th>
<th>-40</th>
<th>-20 (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Energy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P...QL</td>
<td>27</td>
<td>30</td>
<td>35 (J)</td>
</tr>
<tr>
<td>P...NL</td>
<td>27</td>
<td>30</td>
<td>(J)</td>
</tr>
</tbody>
</table>

4.4 Fittings and accessories
Fittings may be supplied according to ASME specification SA-234 Gr WPB (or DIN EN 10253-2 grade P235GH, P265GH).

If fittings and accessories (valves, flanges,...) are made of carbon steel castings, ASTM SA-216 Gr WCB (or grade GP240GH according to EN10213) could be used.

If low temperature service is specified, fittings requiring notch toughness testing may be supplied per ASME specification SA-420 Gr WPL6 (or DIN EN 10253-2 grade P265NL,
P355NL1). Castings may supplied per ASME specification SA-352 Gr LCB (or EN 10213 grade G17Mn5).

### 4.4.1 Chemical analysis

In addition to the requirements of material standard specification, the specific values exposed for plates shall be fully applied with a Carbon Equivalent maximum value at 0.45wt% except castings for which 0.50wt% is acceptable.

### 4.4.2 Impact test properties

For CS the requirements for impact test value must follow those defined in EN 10523-2 (minimum 27J at 0°C) for fittings and those defined in EN 10213 (minimum 27J at 20°C) for castings.

For LTCS the impact test requirements done at a temperature not higher than MDMT, follow the corresponding code but is not less than 27J at -40°C.

### 4.5 Heat exchanger tubes

The tubes of heat exchangers and condensers may be supplied according to ASME specification SA-179 (or EN 10216-2 + A2 grade P235GH, P265GH).

If low temperature service is specified, tubes requiring notch toughness testing may be supplied per ASME specification SA-334 Gr 6 (or EN 10216-4 grade P265NL, P265QL).

#### 4.5.1 Steel making process

The seamless tubes have to be delivered in normalized conditions (including final normalization for cold drawn tubes).

#### 4.5.2 Chemical analysis

In addition to the requirements of material standard specification, the specific values exposed for plates shall be fully applied with a Carbon Equivalent maximum value at 0.45wt%.

#### 4.5.3 Impact test properties

For CS the requirements for impact test value must follow those defined in EN 10216-2 + A2 (minimum 27J at 0°C).

For LTCS the impact test requirements must follow those defined for seamless piping (paragraph 4.3.3).
5. WELDING

5.1 General

The vessel Manufacturer shall not subcontract fabrication involving welding to others without the written approval of the Contractor.

The plate, or forging edge preparation for welding as well as the nozzle openings will be carried out by machining. Flame cutting may be allowed by the Contractor provided the heat affected zone is completely removed by machining or grinding (ex: Nozzles openings in shell or head).

5.2 Welding Processes

Welding processes are:
- SAW: Submerged Arc Welding
  The Manufacturer and brand name or grade of all welding consumables shall be specified in the welding procedure and submitted to the Contractor for approval.
- SMAW: Shielded Manual Arc Welding
  Only low hydrogen electrodes shall be used (refer to ASME II Part C SFA 5.1).
  Dedicated procedure for electrodes drying/conditioning shall be submitted to Contractor for approval.
- GTAW: Gas Tungsten Arc Welding
  (mainly for nozzles)

Remark:
- FCAW : Flux Cored Arc Welding may be considered at the acceptance of Owner and/or Engineering Contractor.
- GMAW : Gas Metal Arc Welding may be used for welds not subject to pressure.

Notes
- All the pressure retaining welds in hydrogen service, including the internals welded on pressure parts, have to be full penetration type. If this is not possible, there will be a vent drill-hole of the not welded area. External attachments are not concerned.
- Only approved WPS with WPQR are to be used for fabrication. Welding procedures submitted to the Contractor shall include details variables and welding parameters for each used welding process. Qualification test shall be made using filler metal, flux and/or inert gases of same type, brand, chemistry and size as the ones to be used on work.
- Coupons to be used for Qualification test shall be heat treated in the same manner as specified for the plate test as given in §4.1.3.
5.3 Welding Consumables Chemical Analysis

The deposited weld metal shall basically match with the nominal chemical composition of the base material as specified in ASME Section II, Part C for the selected electrodes. The mechanical properties of the deposited weld metal shall meet those of the base material.

Material Certificates shall be delivered for each batch, lot, diameter of covered electrodes, wire/flux combination to be used for fabrication.

Note

A procedure for flux conditioning so as to guarantee a potential diffusible hydrogen content consistent with the recommendations of the welding consumables manufacturer shall be submitted to Contractor’s approval. As the same manner, the procedure for electrodes conditioning shall also be submitted for approval.
6. CLADDING OR WELD OVERLAY

6.1 Cladding

High alloy clad materials shall be in accordance with the ASME Section II, Part A, Specification SA-264 for Chromium-Nickel Steels.

Cladding shall be 3mm minimum thickness SA-240 or as specified on the drawings. A 140MPa minimum shear strength per SA-264 is required. The clad plate shall be ultrasonically examined in accordance with SA-578 supplementary requirements S7 using Level 1 acceptance criteria.

6.2 Weld Overlay

Generally speaking (when clad is specified as SS 321 or SS 347, or overlay is specified as SS 347, on data sheet), the weld overlay is applied using a two-layers technique as follows:

- First layer: 309L SS
- Second layer: 347 SS (type SS321 shall be not permitted)
- Minimum effective thickness of undiluted alloy (after final machining if any) shall be that required on equipment data sheet specification.

However, single layer weld deposit overlay (type 309LNb as typical) may be used provided the fabricator can demonstrate to the contractor the use of a qualified and acceptable procedure.

**Note 1**

When clad is specified as SS 316Ti or overlay is specified as SS 318 on data sheet, the weld overlay is applied using a two-layers technique as follow:

- First layer: 309LMo SS or 309L SS
- Second layer: 318 SS (309LMoNb as typical for single layer)

When clad is specified as SS 317L or overlay is specified as SS 317L on data sheet, the weld overlay is applied using a two-layers technique as follow:

- First layer: 309LMo SS or 309L SS
- Second layer: 317L (Single layer not allowed)

**Note 2**

The number of weld layers in production shall not be less than the number of layers deposited for weld overlay procedure qualification tests.

When required by the Owner/User, a method to evaluate the weld overlay for susceptibility to hydrogen disbonding shall be agreed between the fabricator and owner/user. In such a case, the Owner/User shall define testing requirements and acceptance criteria.
An example of a standard disbonding test may be found in ASTM G 146.

Welding processes are the same than in paragraph 5.2, using strips or wires for SAW process.

GMAW process is not allowed, except for structural attachments welding on overlay.

FCAW with gas shielding may also be used for some limited location such as overlay on CS joint, internal support rings, etc.

Both of GMAW and FCAW processes shall be authorized by the Contractor. As the same manner, the use of Electroslag (ESW) process remains subject to Contractor’s acceptance.

### 6.3 Ferrite Content

The ferrite content (FN) of the weld deposits determined by the as-deposited chemical composition and the WRC-diagram, will be less than 8, but more than 3 to prevent hot cracking.

In addition, the ferrite content can be checked by a magnetic ferriscope. In that case, the acceptance criteria shall be 3% to 10%. Magnetic instrument shall be calibrated and certified per AWS A4-2.

### 6.4 Nozzles and Manways

Nozzles and manways (neck, flange, blind) in clad vessels, or in clad section of vessels, shall be of the same base material as the vessel and internally clad, or overlaid, with the same high alloy.

Loose lining, lap-joint flanges, welding of nozzle of different material than the vessel is not permitted.

The thickness of the cladding or overlay shall be at least equal to that of the cladding or overlay of the vessel.
7. POST WELD HEAT TREATMENT BY VESSEL FABRICATOR

The equipment shall receive PWHT in accordance with ASME table UCS-56 ASME VIII Div 1 and §6.4.2 for ASME VIII Div 2 and/or applicable code cases.

In addition to this and as general rule for hot hydrogen service (operating temperature above 220°C), Axens recommends to perform a PWHT for corrosion reason even if not imposed by code. Other services (caustic, fluorhydric acid, carbonate in alkaline conditions, methanol, ethanol, ammonia,...) require also similar PWHT to prevent stress corrosion cracking.

PWHT may also be mandatory for stress relieve, even if not imposed by code, if CS vessel will be internally coated against corrosion (i.e. Fiber Reinforced Polymer coating).

All weldings (base metal or first layer of weld overlay) will be completed before final PWHT.

Thermal Stress Relieving is also required for all cold bend zones in hot hydrogen service. Level of deformation may require recovery annealing to restore properties of steel.

ASME VIII Div 1 in table UCS-56.1 (or ASME VIII Div 2 in table 6.16) allows to reduce the temperature for longer holding time. This is rejected by Axens, as for corrosive services this does not relieve efficiently the residual stresses.

Unless otherwise specified by steel maker the normal holding temperature is 605 ± 10°C. Holding time to be determined by reactor manufacturer according to wall thickness and Code. Temperature shall be measured by thermocouples, placed on the equipments being heat treated. Heat treatment shall be recorded on time/temperature chart.

Local PWHT shall be normally not permitted. In case of any furnace size limitation or limitation due to transportation, vessel Manufacturer shall obtain specific derogation from the Contractor to perform local PWHT at the closing seams of shell. Only this type of weld will be allowed for local PWHT.

PWHT as described above is also applicable for equipments in wet H₂S and sour water services covered by Axens IN-043, additionally to current specification IN-042.0.
8. NON DESTRUCTIVE EXAMINATION BY VESSEL FABRICATOR

This document covers a wide range of equipments. Its first purpose is the specification of material. Only main guidelines are given for Non Destructive Examination (NDE).

For vessels designed and constructed in accordance with the rules of ASME Section VIII, Div.1, Inspection Plan and Testing Plan shall be submitted to Engineering Contractor for approval.

For vessels designed and constructed in accordance with the rules of ASME Section VIII, Div.2, Non Destructive Examination as a minimum shall comply with the Table 7.2 of ASME document.

Depending on service conditions, the minimum requirements for NDE of pressure welds should typically include the following:

<table>
<thead>
<tr>
<th>Service conditions (exclusive)</th>
<th>RT</th>
<th>UT</th>
<th>MT</th>
<th>PT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Thickness&lt;10mm</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>all welds</td>
</tr>
<tr>
<td>Design pressure&lt;5 barg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No H₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No lethal compounds</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Thickness 10&lt;&lt;50mm</td>
<td>spot (a)</td>
<td>no</td>
<td>no</td>
<td>all welds</td>
</tr>
<tr>
<td>Design pressure 5&lt;&lt;50 barg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂ service ≤ 220°C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Thickness 10&lt;&lt;50mm</td>
<td>spot (a)</td>
<td>all welds</td>
<td>no</td>
<td>all welds</td>
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<tr>
<td>Design pressure 5&lt;&lt;50 barg</td>
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<tr>
<td>H₂ service &gt;220°C</td>
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</tr>
<tr>
<td>4 Thickness ≥ 50mm</td>
<td>all welds</td>
<td>all welds</td>
<td>all welds</td>
<td>all welds</td>
</tr>
<tr>
<td>Design pressure ≥ 50 barg</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>H₂ service &gt;220°C</td>
<td></td>
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</tr>
</tbody>
</table>

(a) all welds if H₂S, HF, COS or any other lethal compounds is present.

Radiographic examination (RT) applied to service conditions 2, 3 and 4, is performed if needed prior to PWHT only, provided that UT is made before and after PWHT (except conditions 2). RT is not so effective after PWHT for detecting potential cracks. RT is sensitive for volumetric flaw such as slugs inclusion but not sensitive for shape cracks which could appear during PWHT. Nevertheless, the final decision, relative to RT examination sequences, belongs to the Contractor.

Ultrasonic examination (UT) applied to service conditions 3 and 4, is performed prior and after PWHT and after hydrotest.

Magnetic Particles Examination (MT) applied to service condition 4, is performed after PWHT.
Dye penetrant examination (PT) of all welds and weld overlay surfaces after PWHT whatever the service conditions.

If Vendor can duly establish that weld-overlay has been performed continuously, thus guarantying that no change in welding conditions has been encountered while depositing on vessel shell, then PT could be performed on some representative weld overlaid width lines only. Procedure’s acceptance shall be submitted to Owner/Contractor decision. Whatever the approved procedure will be, 100% complementary visual inspection always remains mandatory.

In addition, Positive Material Identification (PMI) on all alloyed material if any, is recommended (cladding, overlay, etc.).

Major defects, such as cracks, lack of fusion or others leading to weld repair shall be officially notified to contractor though Non-Conformance report to be considered within the QA/QC procedure. Proposed repairing procedures shall be submitted to the contractor for acceptance.

Hydrostatic test shall be performed after completion of all internal and external welding.
9. VESSEL AGEING SURVEY

In the aim at being able to evaluate the vessel ageing in after long term operations (i.e. graphitization), it is recommended to install some dedicated and representative coupons (quantity: 2) into the equipment to be operated even occasionally above 428 °C.

These coupons shall be issued from plate used for the vessel itself (and showing one representative heat of shell). Coupons shall be thought in term of design to be similar with the shell wall behavior. Coupons shall consequently be made from two independent parts welded by using the same WPS and weld preparation as the ones used for shell longitudinal seams.

In case of weld overlaid (or cladded) vessels, each surface of the coupons shall also be weld overlaid (or cladded) using same specification/procedure as for shell itself (steel grade and thickness as per specification).

Moreover, coupons have to be properly localized into the process main stream so as to be submitted to process operating conditions as the pressure retaining parts will.

Unless otherwise specified by Owner and/or Engineering Contractor, the design and positioning of the coupons will be proposed by the Vessel Vendor and submitted to Axens approval so as to insure that any detrimental interference with fluid flow will not occur.