TECHNICAL SPECIFICATION

EQUIPMENT MADE OF 2.25 Cr-1 Mo STEEL IN QUENCHED AND TEMPERED CONDITION

W-6-1/2/3

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DESIGN AND ENGINEERING PRACTICE

USED BY

COMPANIES OF THE ROYAL DUTCH/SHELL GROUP

PREFACE

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TABLE OF CONTENTS

APPENDICES

1. INTRODUCTION

1.1 GENERAL

This specification contains minimum requirements for the material, fabrication, production tests and non-destructive testing of equipment for hydrogen service, fabricated from 2.25 Cr - 1 Mo steel with or without austenitic stainless steel cladding.

It is intended for use in oil refineries, chemical plants, gas plants and, where applicable, in exploration, production and new ventures.

Unless otherwise authorized by SIPM, the distribution of this specification is confined to companies belonging to or managed by the Royal Dutch/Shell Group, and to contractors and manufacturers/suppliers nominated by them.

As a rule the requirements of this specification shall be adhered to.

However, national and/or local regulations may exist in which some of the requirements are more stringent.

The contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable as regards safety, economic and legal aspects.

In all cases the contractor shall inform the principal of any deviation from the requirements of this specification which is considered to be necessary, in order to comply with national and/or local regulations. The principal may then negotiate with the authorities concerned with the object of obtaining agreement to follow this specification as closely as possible.

The publications referred to in this specification are mentioned in Section 10.

Where cross references are made, the number of the section or sub-section referred to, is shown in brackets.

1.2 DEFINITIONS

For the purpose of this specification the following definitions shall hold:

Shall and **Should** - The word 'shall' is to be understood as mandatory and the word 'should' as strongly recommended to comply with the requirements of this specification.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction.
The principal wil generally specify the technical requirements.
The Principal may also include an agent or consultant, authorized to act for the Principal.

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, construction and commissioning for the project. The Principal may sometimes undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party which manufacturers or supplies equipment and services to perform the duties specified by the Contractor.

The **Purchaser** is the party which buys equipment, materials and/or services for its own use or as agent for the owner. The Purchaser may be either Principal or Contractor.

2. MATERIALS

2.1 BASE MATERIAL: PLATE

2.1.1 Chemical composition

The chemical composition of the plate material shall be in accordance with ASTM A 387 Gr. 22, with the following additional chemical requirements:

Cu content : 0.20% max.

Ni content : 0.30% max.

$(\%Si + \%Mn) \times (\%P + \%Sn) \times 10^4 \leq 180$

Vacuum degassed, aluminium-killed steel is required.

2.1.2 Heat treatment

The steel shall be in the quenched and tempered condition.

The aproximate heat treatment temperature ranges are:

Austenitizing temperature : 940-960°C

Tempering temperature : 680-720°C

The cooling rate after austenitizing shall not be lower than 5°C/min.

2.1.3 Mechanical properties

- Tensile properties
  The tensile properties (specimens at $^1/_4$ and $^1/_2$ of the plate thickness) shall meet the requirements as per ASTM A 387 Gr. 22, Class 2 .
- Hardness
  The maximum hardness shall not exceed 248 HV 20.
- Impact values (Charpy-V)
  The minimum individual impact values (Charpy-V) of plate material in the quenched and tempered condition in transverse direction for specimens at $^1/_4$ and $^1/_2$ of the plate thickness and at a temperature of -40°C shall not be less than 55 J.

  A step cool treatment test as specified in (3.2.2) shall be carried out for each heat of plate material.

  After this treatment, impact properties (Charpy-V at $^1/_4$ and $^1/_2$ of the plate thickness) shall meet the following requirement:

  $$T_{55} + 3\,\Delta T_{55} < 10°C$$

  Where:

  T_{55} = the 55 Joule transition temperature of the quenched and tempered plate subjected to the maximum number of heat treatments as envisaged for the vessel during fabrication including repairs.

  ΔT_{55} = the shift of 55 Joule transition temperature of the quenched and tempered plate subjected to the maximum number of heat treatments as envisaged for the vessel during fabrication including repairs.

Properties at higher temperatures shall be as agreed upon by the purchaser/manufacturer and local instance. (For temperature and applied stress refer to the applicable requisition.)

The short time tensile properties at design temperature shall be met by specimens taken at $^1/_2$ of the plate thickness, apart from governing code requirements concerning position of test specimen. The tensile testing shall be performed in accordance with the code requirements and ASTM A 370.

The plate manufacturer shall guarantee that the minimum physical properties specified are still being met after all heat treatments envisaged during fabrication of the vessel. For this purpose test sections from one end of each plate furnished shall be removed.

The complete heat treatment, as used during fabrication of the vessels plus one extra stress relief annealing, see (2.1.2), shall be applied for these test sections. Thereafter mechanical testing is to be carried out.

The results of these tests shall be handed over to the purchaser before the actual start of fabrication of the vessel.

2.1.4 Ultrasonic testing of plate material

All plates shall be ultrasonically tested using a technique in accordance with ASTM A 578 or BS 5996. Acceptance criteria shall be as per BS 5996 - LC4 ES.

2.1.5 Repair welding

Plate defects may be repaired by welding, if acceptable to the inspection authority and prior approval has been obtained from the purchaser of the vessel. Repaired areas shall have full ultrasonic and magnetic particle inspection. Accurate records of the location of all plate repairs shall be made for future reference.
Plate repairs shall be made by ASME IX qualified welders and welding procedures.

2.1.6 Plate thickness

Undertolerance is not acceptable. Plate thicknesses as specified are minimum thicknesses. The manufacturer shall ensure that metal loss from scaling, decarburization, forming, fusion (penetration) due to overlay welding etc. does not encroach on minimum thickness.
It should be anticipated that in the case of back-welding of roll-bond clad material additional base (-weld) material will be ground away in order to allow for overlay welding according to the two-layer system.

2.1.7 Marking and certification

Each plate shall be marked in accordance with applicable code requirements. All excess material from each plate shall be identified by the plate manufacturer and shipped together with the plates to the manufacturer of the vessel.
For further requirements for marking and certification see DEP 30.10.02.10-Gen., 'Quality of materials'.

2.2 BASE MATERIAL: FORGINGS

2.2.1 Non-pressure parts

Forgings shall be made from material which has the same chemical composition as the plate material, with the additional requirements as per (2.1.1). The forgings shall be in the quenched and tempered condition and shall comply with the mechanical requirements stated in (2.1.3).

NOTE: ASTM specification A 182 Gr. F 22 and A 336 Gr. F 22 are all considered equivalent to A 387 Gr. 22 plate material.

2.2.2 Pressure parts

All forgings used for pressure parts, except ANSI standard size nozzles and flanges produced in existing contour dies, shall conform to ASTM A 336 in addition to the requirements outlined herein. The vessel manufacturer shall be responsible for supplying forgings which meet all the requirements of this specification.
If the forgings are not manufactured by the vessel manufacturer, the forging manufacturer shall be approved by the purchaser before orders are placed.
All forgings shall be ordered forged from steel made by the electric furnace process. Vacuum degassed, aluminium-killed steel is required. The forgings shall be in the quenched and tempered condition. Additional chemical requirements as per (2.1.1) and mechanical requirements as per (2.1.3) shall be satisfied. Impact specimens at $^1/_4$ of the plate thickness shall be taken from the inner surface of the forging.

In addition to the requirements of ASTM A 336, the following provisions shall apply:

(a) The forging manufacturer shall choose a method of working that will minimize directionality as evidenced by micro-etching or as evidenced by the mechanical properties. All forgings shall be contour-forged, i.e. the material will be brought close to the finished shape by hot-forming as far as practicable.
The production of forged parts by cutting and/or machining from a longitudinally forged billet or bar is not acceptable, and parts produced in this manner shall be rejected.
The forging manufacturer shall report the size of billet (or ingot) used for each part, the final reduction in cross-sectional area and amount of upsetting with respect to the billet (or ingot), and the complete heat treating procedure.
This information shall be submitted with the quotation as well as with the final data required for each order.

(b) The forging temperatures and reductions used shall be consistent for forgings of similar size. Post-forging practice shall be such that surface cracking or thermal flaking is prevented.

(c) The forging manufacturer shall report all heat treating cycles.
This report shall contain as a minimum temperatures, holding time at temperature, heating and cooling practice for each furnace charge of forgings, including the piece numbers involved.

(d) All forgings shall meet the same additional properties as specified in (2.1.3) for the plate material.
Therefore, provisions shall be made to remove extra test coupons from the forging, which shall be subjected to the complete heat treatments envisaged for the fabrication of the vessel. Mechanical tests shall be carried out and the results shall be handed over to the purchaser before the actual start of the fabrication of the vessel.

(e) All forgings, except those produced in standard dies, shall be machined after heat treatment and prior to final magnetic particle, fluorescent penetrant inspection in accordance with ASME VIII, Division 2, Appendix 9, and ultrasonic examination. The finish shall be Ra 6.3 ;m or smoother.

(f) Test specimens shall be removed from full size prolongations of each forging, as directed by ASTM Specification A 336. Mechanical testing shall be performed in accordance with ASTM A 370, and specimens shall be removed in accordance with Figure 2 of ASTM A 370 specification for tangential testing.

All forgings larger than 50 mm nominal bore shall be individually tested. For forgings of 50 mm nominal bore, one specimen shall be tested for each lot of forgings heat-treated in one batch, provided that such forgings are produced from the same heat of steel.

(g) Drum forgings for forged pressure vessel shells with a length of > 1800 mm, open at either one end or both ends, shall have test specimens removed from full-size prolongations of the open end. (If open at both ends, test specimens shall be removed from full-size prolongations of both ends.) Sufficient material shall be provided for the production tests on the base material as specified in (4.1.2).
The specimens governing acceptance of the forging shall be removed from the diagonal corners of an axial plane, as described in paragraph 8.2 of ASTM A 336.
Vessel shells with integrally forged bottom heads shall have the 'head-end' test specimen removed from a prolongation of the head-end and the specimen shall be located as if it were being removed from a prolongation of the shell. The specimen location shall be approved by the purchaser.

2.2.3 Ultrasonic testing

All forgings shall be 100% ultrasonically tested in accordance with ASTM A 388 with longitudinal and shear wave techniques. Rejection levels shall be as specified in paragraph AM 203 of Section VIII Div. 2, of the ASME Boiler and Pressure Vessel Code.

2.3 CLADDING AND INTERNALS

The chemical composition of cladding and internals shall be as specified in the requisition sheet.
All shell components shall be integrally clad by means of roll-bond cladding or explosion cladding.
Where this is not possible, overlay welding may be considered and applied after the purchaser's approval. If overlay welding is applied, a two-layer system shall be used.
The clad plates shall conform to ASTM A 264, including the shear-strength test.
Cladding shall be examined on disbonding over 100% of the surface area according to ASTM A 578 with acceptance level S6.

In addition the following requirements must be fulfilled:

- The total of the unbonded areas between 625 mm^2 surface and those which can be encompassed by a 76 mm diameter circle shall not exceed 0.025 m^2 per 1 m^2 area of plate (areas less than 625 mm^2 shall be ignored).
- Any cut edge shall be 100% tested over a band-width not less than 75 mm wide and in this band no defects are acceptable.

Cladding repair welding shall be performed by ASME IX qualified welders and welding procedures. Procedures shall be approved by the principal.

Internal grid support rings (e.g. for catalyst beds) shall be deposit-welded on the bare base material with 2.25 Cr-1Mo steel weld metal, and be machined.
Thereafter, these deposit-welded rings shall be overlay-welded with at least 2 layers of the required weld metal, and machined to the final dimensions.

Internal flanges (such as for quench decks) shall be made from forged material.

3. FABRICATION

3.1 FORMING AND ASSEMBLY

The internal diameter of heads and shell shall be identical.

The manufacturer shall take all precautions to minimize plate damage due to scale formation during heating, see (2.1.6).
Any such damage shall be repaired after approval from the principal.

If hot forming is applied, austenitizing, quenching and tempering shall be carried out after hot forming.
If the longitudinal welds are electro-slag welded, austenitizing, quenching and tempering shall be carried out after electro-slag welding.

The preparation of plate edges for welding shall be effected by machining or by flame cutting.
In the case of flame cutting pre-heating shall be applied and heat-affected zones shall be removed by grinding.

Each shell section shall be completely welded longitudinally and corrected for out-of-roundness and peaking of the weld seam prior to assembly. Corrections shall not be made until the welds have received a post-weld heat treatment, see (3.4).
Likewise, all re-rolling or forming of the shell sections shall be completed prior to radiographic and ultrasonic examination.

Nozzles shall be flush and ground smooth with the internal surface. The inside edge of nozzles shall be rounded to a minimum radius of 6 mm.
The external attachment welds shall provide a smooth transition between vessel surface and nozzle neck, with the transition having a minimum radius of 20 mm.

Nozzle-to-vessel attachment design shall be in accordance with ASME Section VIII, Division 2, Figure AD-613.1(c), (c-1), or (d), except that integrally reinforced nozzles conforming to Figure AD-610.1 (c), (d) or (e) may be used, provided that acceptable radiographs of completed welds are obtained. The final nozzle contour shall be obtained by forging, except that finish-detail machining is permissible, see (2.2.2 a).

Nozzles shall be assembled in such a way that during welding there is at least 300 mm of solid base material present between a nozzle weld and any other shell or nozzle weld that has not yet been heat-treated.

If the layout of nozzles is such that these 300 mm cannot be maintained, the following sequence shall be adhered to:

- Cut only those nozzle openings which allow the 300 mm solid material in between. These nozzles shall be welded into the vessel and after welding a post-weld heat treatment (PWHT) shall be performed, see (3.4).
- Thereafter further nozzle openings shall be cut out and the nozzles welded in, thereby again adhering to the above-mentioned requirements for weld distances and PWHT.
  These steps shall be repeated until all nozzles are assembled.

If a skirt support is specified, it shall be attached to the shell or bottom head via a built-up ring, deposit-welded on the shell or bottom head and machined to contour (see Appendix 1 and Standard Drawing S 20.001). Built-up rings shall be inspected ultrasonically, see (4.3), and by magnetic particle examination, see (4.4), after machining and before attachment of the skirt.

The upper part of the skirt shall be of the same chemical composition as the vessel material. It shall be fabricated from plate with such an overthickness that the required minimum thickness is not exceeded after machining of the welding edge which is required for perfect fit-up with the weld-deposited ring on the shell or bottom head. The joint between skirt and ring shall be welded from the outside only, see (3.2.1).

Non-destructive testing of skirt welds shall be agreed upon between purchaser and manufacturer.

Attachments

(a) Temporary attachments such as aids for handling and fitting may be welded to the base material, using a preheat of 150-200°C and using 2.25 Cr - 1Mo steel electrodes. After welding, slow cooling shall be executed.

Before final heat treatment, temporary attachments shall be removed by cutting above the weld and grinding down to the original plate surface. The area shall be magnetic particle tested and if necessary be repaired with the proper repair procedure, see (3.2).

(b) No permanent structural attachments except as shown on the applicable drawings shall be welded to the outside of the shell of the vessel. Structural attachments to the outside of the vessels shall be of the same chemical composition as the base material.
Attachments (other than those mentioned under 2.3) welded on the inside cladding of the vessel shall have the same chemical composition as the final layer of the cladding.

(c) The vessel shall be provided with attachments for corrosion test blocks. The number and size of the test blocks shall be specified by the principal.

3.2 WELDING

3.2.1 General

All welding, including temporary attachment welding, shall be done in accordance with Section VIII, Division 2, of the ASME Boiler and Pressure Vessel Code and/or the applied design code, whichever is the more stringent. No welding shall be allowed until procedures qualified in accordance with the applicable code and this specification have been approved by the purchaser. The manufacturer shall submit with his quotation, for information only, all welding procedures, including repair welding.

Shielded metal arc welding, TIG welding, submerged arc welding and electro-slag welding may be used. Welding materials shall be approved by purchaser.

For automatic welding of the base material, the alloy additions of Cr and Mo in the flux are not permitted. The use of flux-filled core-wire is also prohibited.

The combination of wire and flux shall have the approval of the flux supplier with respect to compatibility of these welding materials. For production welding the same brand and type of flux and wire shall be used as in the procedure test.

The combination of welding wire and flux for submerged arc welding shall require the special approval of the purchaser of the vessel. The manufacturer shall maintain strict control over dispersal and shall record distribution of all welding materials, so that heat, lot and bake numbers of material used in any weld can be identified.

A wet chemical analysis, see (3.2.2), shall be carried out for each coil of wire and batch of electrodes used. Records including name of supplier, heat number and chemical composition shall be kept and traceability to the exact location in actual welds shall be guaranteed for each coil of wire and batch of electrodes.

In addition a sample of each coil of wire used for circumferential welds, internal support rings and all other permanent attachments shall be retained.

Starting and run-off pads shall be used when welding longitudinal seams and shall be of the same chemical composition as the base materials.

All welded joints, including permanent attachments and the longitudinal and circumferential seams of skirts, shall be double-welded with full penetration, with the exception of the joint from the skirt to the built-up ring on shell or bottom head, which shall be one-side welded with full penetration.

All nozzle and manway necks shall be attached by welding completely through the total thickness of the vessel wall, see (3.1).
The location, size and depth of all repair welds shall be recorded. Locations shall be plotted on drawings.

3.2.2 Plate welding procedure qualification

Test plates for welding procedure qualification tests shall be of the same material (i.e. same heat) and thickness as the vessel plate material and shall have had the same heat treatments.
The procedure test plate shall be tested in accordance with the applicable code as well as with the requirements of this specification, whichever is the more stringent. Before any destructive testing is executed, the welds shall be non-destructively tested as specified for the vessel.

The deposited weld metal shall match the chemical composition of the base material in respect of Cr and Mo. Wet chemical analysis of each heat number of welding consumables to be used on the vessel for welding shall be made by the vessel manufacturer. This analysis shall include:
C - Mn - Si - P - S - Cu - Ni - Cr - Mo - Sb - Sn - As - Ti and V, see (3.2.1).
The same elements shall be analysed for the deposited weld metal in the procedure qualifications at 1/2 and 1/4 thickness for all welding procedures.

The applicable acceptance criteria are as follows:

$$\frac{10P + 5Sb + 4Sn + As}{100} \leq 20 \text{ ppm}$$

and :

$$\% \text{ Mn} + \% \text{ Si} \leq 1.1\%$$

Physical properties, i.e. ultimate tensile strength, creep strength, yield strength (0.2% proof stress) at design temperature, elongation and impact test value of deposited automatic and manual weld metal shall not be less than the guaranteed physical properties of the base metal (2.1.3). This shall be demonstrated by means of tests carried out with specimens removed from the test plate which has received all post-weld heat treatments envisaged for the vessel parts and completed vessel (4.1).

The above tests shall be made at both ½ and ¼ of the wall thickness.
Impact tests shall be made with the notch in the centre of the weld and with the notch in the heat-affected zone. The impact specimen shall be taken in the cross-direction of the weld. The notches shall be perpendicular to the plate surface.

A Vickers hardness survey (20 kg load) shall be made on a cross-section through the weld (including the heat-affected zone) after having received all post-weld heat treatments envisaged for the vessel parts and completed vessel at 2 mm below the surfaces and ¼ and ½ of the plate thickness. The hardness shall not exceed 248 HV 20.

In order to test the sensitivity to temper embrittlement of the weld metal and the heat affected zone, the manufacturer shall establish 'Charpy V' impact transition curves (specimen positions as indicated above) of:

(A) The weld subjected to the complete number of heat treatments as envisaged for the vessel during fabrication.

(B) The weld subjected to the complete number of heat treatments as envisaged for the vessel during fabrication followed by a step cool treatment as specified below.

The step cool treatment is as follows:

Hold at 595°C for 1 h; then cool at 5°C/h to next temp.
Hold at 540°C for 15 h; then cool at 5°C/h to next temp.
Hold at 525°C for 24 h; then cool at 5°C/h to next temp.
Hold at 495°C for 60 h; then cool at 5°C/h to next temp.
Hold at 470°C for 125 h; then cool at 20°C/h to 400°C
and subsequently completely cool in air.

The shift between the impact transition curves of the weld before (condition A indicated above) and after step cool treatment shall comply with the requirements as laid down in (2.1.3) for base metal.

3.2.3 Overlay welding procedure qualifications

The weld overlay procedures shall be qualified in accordance with Paragraph AF-522 and AF-541 of ASME Section VIII Division 2, on base metal of the same composition, same mechanical properties and same surface condition as the base material to be used in production. The thickness of the plate for procedure qualification shall not be less than half the thickness used in production and shall have had the same heat treatments.

Welding materials, overlay thickness, preheat and post-weld heat treatment times and temperatures used on the overlay qualification test plates shall be the same as those used in production.

The entire surface of the base metal to be overlaid, shall be ground to clean bright metal.
The overlay welding procedure shall be developed so that the overlay surface shall be relatively smooth (waving is permissible but without notches, undercuts, etc., that would act as stress raisers). The overlay welds shall be applied in such a way that the weld beads are circumferential to the vessel or pipe being overlaid unless otherwise agreed. The interface between base metal and overlay shall be prepared by grinding where necessary to eliminate pockets, sharp notches and other flaws which would prevent full bonding of the overlay material.

For wire/flux overlay weld consumables a procedure qualification test is required. The wire manufacturer shall state in writing that the wire/flux combination gives the required weld deposit as regards chemical composition.

The overlay welding procedure to be applied shall use a two-layer technique. (First layer to be welded with a buffer filler-metal.) The ferrite content of the overlay weld shall be within the range of 3 to 7%, determined by optical metallography in the welding procedure test plate. This determination shall be carried out for the three standard metallographic sections.

At least 2 mm of the top layer shall meet the requirements for chemical composition of the type of austenitic steel specified in the data requisition sheets.

The overlay shall be considered to be the corrosion allowance of the vessel and as such the overlay and fusion zone shall not be considered part of the shell for strength purposes. The maximum overlay thickness shall not exceed 10 mm or 25% of the base metal thickness, whichever is the smaller.

The wet chemical analysis of the overlay on the test plate shall be determined at two separate locations and at two depths (measured from the overlaid surface at 1 and 2 mm respectively) and shall conform to the requirements specified. The samples shall be taken by milling or chipping

3.3 PREHEAT AND INTERPASS TEMPERATURE

3.3.1 Base metal welds

The A 387 Gr. 22 base metal shall be preheated to 150-200°C and maintained at this temperature during flame cutting, welding, arc gouging and other thermal applications. The pre-heating temperature shall be maintained during and after welding until a post-weld heat treatment has been performed, see (3.4).

3.3.2 Overlay welds

The A 387 Gr. 22 base metal shall be preheated to 100°C minimum before the first layer of the stainless steel weld overlay is deposited. Provided that subsequent slow cooling is applied, an intermediate post-weld heat treatment can be omitted after overlay welding.

Welding of austenitic stainless steel attachments to the austenitic overlay may be executed without preheating and without intermediate post-weld heat treatment, provided that the limitations of paragraph 3.4 are met.

3.4 POST-WELD HEAT TREATMENTS

After all welding operations a post-weld heat treatment shall be performed without cooling down below the preheating temperature.
If for fabrication reasons the ultimately required heat treatment is not performed directly after welding, an intermediate post-weld heat treatment at a temperature within the range of 600-650°C shall be carried out. Holding times shall be as per Table UCS-56 of ASME Section VIII, Division 1.
For circumferential and longitudinal seams of vessels a hydrogen removal heat treatment step at 300°C is acceptable.
However, nozzle welds shall always receive an intermediate post-weld heat treatment.

All welding to base metal, including clips, structural parts and surface repairs as well as welding of attachments referred to in (3.3.2) shall be completed prior to the final post-weld heat treatment.

NOTE: Welding of (minor) austenitic stainless steel attachments to the austenitic stainless steel weld overlay after the final post-weld heat treatment is permitted provided that the thickness of the weld overlay is 5 mm minimum.

The manufacturer shall provide in his quotation complete information on temperature and soaking period for austen tizing, quenching and tempering after electro-slag welding, and for both the final heat treatment and possible intermediate heat treatment envisaged. Soaking periods shall be based on the heaviest welded section, including the total thickness of the vessel wall.
The minimum soaking time shall be one hour per 25 mm of thickness for tempering after quenching and for final post-weld heat treatment. Heating-up and cooling down rates shall be in accordance with ASME VIII, Division 2, AF 415. The intermediate post-weld heat treatment temperature shall be within the 600-650°C range.

Manufacturer's post-weld heat treatment procedures shall be approved by the purchaser.

3.5 FABRICATION TOLERANCES

All tolerances shall be in accordance with the applicable code, except as modified in the following paragraph.

Alignment tolerance of butt welded joints in material with wall thickness over 100 mm:

(a)	Longitudinal joints	Max. offset - 6 mm
(b)	Circumferential joints (including head segments)	Max. offset - 6 mm

4. PRODUCTION TESTS AND NON-DESTRUCTIVE TESTING

4.1 MECHANICAL TESTING OF MATERIAL AND WELDS

Apart from the required testing of plate material at the steel mill, plate material properties shall be checked after hot forming and heat treatment of vessel components, as mentioned below.

All shell courses and heads or head segments hot-formed by the vessel manufacturer or his sub-supplier shall have enough extra material for performing mechanical testing of base material after hot-forming and heat-treating.
For heads this extra material can be taken from the locations where nozzles are to be welded in.
For shell courses the extra material shall be a 'heat-treatment production test plate' (dimensions approx. 300 x 400 mm), welded to the shell course before heat-treating and removed after quenching and tempering.

The test plates attached to the shell ring shall be of the same heat and rolling number as the shell ring and shall be hot-formed under the same conditions as the shell course.

In order to obtain these test plates (and those mentioned below) of material in the same condition as the shell course proper, the shell course plates shall be purchased with an extra length so that, after hot-forming but before closing of the shell course, the test plate material can be cut off, see (Appendix 2). Testing shall be as specified for the base material.

Temperature cycles of the heat treatment shall be recorded with thermocouples. The minimum number of thermocouples shall be as per the applicable ASME code.

Each shell course and each head shall have one production weld test plate attached to it (dimensions approx. 700 x 400 mm), which will be welded together with the longitudinal weld, see (Appendix 3). In those cases where the longitudinal welds are electro-slag welded, the test plates shall be removed after welding and be separately quenched and tempered.
The heat treatment cycle shall be recorded with thermocouples.

All production weld test plates shall be cut in half. One half of each test plate will be subjected to a simulated post-weld heat treatment (i.e. all post-weld heat treatments envisaged for the component/vessel) and be tested as soon as possible. The other halves of the test plates will be heat-treated together with the vessel components and completed vessel. At least one of these half-plates will be tested after final heat treatment. Testing of the production weld test plates shall be in accordance with the requirements for the plate welding procedure qualification (3.2.2).

4.2 RADIOGRAPHIC EXAMINATION

All finished welds shall be 100% radiographed before final heat treatment.

Radiographic examination of base metal welds shall be carried out before the application of the weld overlay.

Radiographic examination shall be in accordance with ASME Section VIII, Division 2, Article 1 - 5 of Part AI (except that ISO or DIN wire-type penetrameters may be used) or the requirements of the applicable code, whichever is the more stringent.

Fine-grain, high definition, high contrast film (e.g. Kodak Industrex MX or Agfa D4) shall be used in conjunction with lead screens.

Film density shall be within the range of 2.0 to 3.0 as determined either by film density specimens or by densitometer. Double film technique shall be used, and each film shall have a density within the range of 1.0 to 1.5.

4.3 ULTRASONIC EXAMINATION

All base metal welds, including nozzle and attachment welds, shall be 100% ultrasonically inspected for longitudinal and transverse defects before and after final heat treatment as well as after hydrotesting, in accordance with ASME Section VIII, Division 2, Article 9-3 of Appendix 9.

Final acceptance of the welds shall be based on the ultrasonic examination after hydrotesting. This final examination shall be witnessed by the principal or his nominee. During production welding, inspection shall be carried out from both the inside and the outside of the vessel.

The completed overlay shall be tested for slag inclusions and for soundness of bonding after final post-weld heat treatment. Scanning shall be executed along grid lines with a 230 mm pitch.
However, cladrestoring itself and cladding next to clad- restoring (over a width of 75 mm), shall be completely tested.
Testing shall be in accordance with ASTM A 578.

Any location which shows a total loss of back reflection or indications of slag inclusions shall be explored to determine the exact dimensions. Slag inclusions longer than 25 mm are not acceptable.
Lack of bonding over an area larger than 625 mm^2 is not acceptable.

4.4 MAGNETIC PARTICLE EXAMINATION

The magnetic particle examinations shall be carried out in accordance with the wet method as per ASTM E-709 and in the following cases:

- Plate edges and all cut edges at nozzle penetrations prior to welding shall be inspected for laminations and/or injurious segregations. Defects shall be repaired in accordance with qualified and approved procedures.
- All back-chipped or back-gouged surfaces
- All permanent attachment welds on the base metal
- All base metal weld surfaces after hydrotesting.

4.5 DYE-CHECK EXAMINATION OF WELD OVERLAY

The entire surface of the overlay shall be dye-checked between layers in multiple layer overlays, and after the final layer has been deposited.

Surfaces examined shall be free of cracks, laps, fissures or other linear defects. Crazing shall be considered to be a linear defect.

Surfaces examined shall be free of circular defects greater than 1.5 mm in diameter.

Any group of circular defects 1.5 mm in diameter or less contained in a 100 mm diameter area which has an aggregate diameter greater than 3D, where D is the diameter of the largest defect in the group, is unacceptable, except where the distance between the defects exceeds 12D.

Areas where defects have been removed shall be reinspected to ascertain the complete removal of the defect.

When repair welding is required after removal of a defect, the completed repair weld shall be reinspected by the dye-penetrant test method and judged by this standard.

After hydrostatic testing, the entire surface of the overlay shall again be dye-checked.

4.6 HARDNESS MEASUREMENTS

Spot checks of plate and weld hardness on the actual vessel parts shall be made and recorded after each heat treatment as a check on changes in physical properties. Such tests shall be made with a portable hardness tester. The test method and equipment to be used shall be approved by the purchaser.

The following hardness tests shall be made:

(a) Three tests per plate

(b) One test per longitudinal seam

(c) Two tests per circumferential seam

(d) One on each weld between nozzle and head or shell and one on each circumferential weld in nozzle necks.

The result of the hardness test on the completed vessel shall not exceed 248 HV 20.

4.7 CHEMICAL ANALYSIS

4.7.1 Base metal weld

Two samples for analysis of the elements C, Mn, Si, Cr, Mo, P, Sb, Sn and As shall be removed from each nozzle weld, each at different depths as designated by the purchaser's inspector.

The material for analysis shall be removed during filling of the joint and not after completion of the joint.

If a production test plate is produced as an extension of a weld, the analysis shall be made of the weld in this plate after completion of the base metal weld, see (3.2.2) and (4.1).

The chromium and molybdenum contents of all samples of welds shall be not less than the specified chromium and molybdenum contents of the base metal. Furthermore the criteria as per (3.2.2) shall be met.

Should the analytical results indicate that improper weld wire has been used, further sampling shall be required at the manufacturer's expense to ensure that all deposits which do not conform to the chemical requirements are removed and repaired in order to meet the specified analysis.

4.7.2 Overlay weld

Two chemical analyses per shell ring and head shall be made of the overlay at locations designated by the purchaser's inspector at depth as indicated in (3.2.3).

If an alloying agent is mixed with the welding flux, each batch shall be certified by the flux supplier to be of the same composition as the batch which was used to qualify the overlay welding procedure. Fused flux shall not be reused.

The type of stainless steel shall be verified by chemical spot testing on all nozzles.

For each batch of consumables the ferrite content and configuration in the actually deposited weld overlay shall be determined by optical metallography.
The content shall be in the range of 3 to 7%.

4.8 HYDROSTATIC TESTING

Vessels shall be subjected to a shop hydrostatic test at a pressure in accordance with the applicable code.

Prior to final inspection and hydrostatic testing, the inside and outside of the vessels shall be thoroughly cleaned and shall be free of all slag, scale, dirt, grit, weld spatter pieces of metal, paint, oil, etc.

All hydrostatic tests shall be made in the presence of an authorized inspector and with his approval. Vessels shall not have been previously tested by the manufacturer.

No preliminary hydrostatic test, regardless of pressure, shall be made on any vessel prior to any required post-weld heat treatment operation.

The metal temperature during hydrotesting shall be between 35 and 50°C.

In the case of clad vessels, the presence of chlorides in the water shall be avoided, as concentration of the chlorides by evaporation of the remnants of test water may cause stress corrosion cracking of the stainless steel. (Therefore, no attempt shall be made to remove remnants of water with hot air, etc.)

However, the chloride content of the water used for hydrotesting shall not exceed the following limits:

- If the vessel has no stainless steel cladding, water containing up to 200 mg/kg chlorides may be used for the hydrostatic test.
- If the vessel has stainless steel cladding and is flushed with condensate or demineralized water immediately after testing, water containing up to 200 mg/kg chlorides may be used for the pressure test. When flushing with demineralized water it is essential to ensure that all surfaces previously wetted during the pressure test are flushed.
- If the water can be fully drained and completely removed immediately after testing, e.g. by mopping up, water containing up to 200 mg/kg chlorides may be used for hydrostatic testing.
- If however, proper drainage is not possible, the recommended practice is to utilize water containing less than 1 mg/kg chlorides, i.e. condensate or demineralized water.

Further to the requirements on chloride content the water to be used for the hydrostatic test shall be free from sediment, i.e. undissolved solids of any description.

After hydrotesting, all water shall be removed and the vessel dried.

All gaskets and bolting < 2 in (50 mm) used for the hydrostatic pressure test but not tightened by means of hydraulic tensioning equipment, shall be replaced by new material before delivery of the vessel.

5. REPAIRS

Repairs shall not be made without prior approval of the repair procedure by the purchaser.

Welding repairs in base metal welds required after post-weld heat treatment shall be re-heat-treated and non-destructively tested in accordance with the requirements of this specification.

Welding repairs in overlay welds shall be re-post-weld heat-treated if the remaining thickness of the overlay after removal of the defect is less than the diameter of the electrode used for the repair.

Each repair of the overlay shall be checked for the ferrite content in accordance with (4.7.2).

After repair, the repaired area and a band of 75 mm width on either side of this area shall be ultrasonically tested for disbonding.

6. INSPECTION

All pressure vessels covered by this specification are subject to inspection during any phase of manufacture by the purchaser and/or owner. Personnel representing either or both parties shall be granted access to the sections of the manufacturer's plant concerned with production (including heat treatment) and inspection of the order.

The material tests outlined in this specification shall be made for quality control and for job records.
They shall not be construed as prohibiting the manufacturer from making additional tests to establish shop and/or field procedures to result in a satisfactory vessel.

The manufacturer shall furnish the necessary gauging and inspection equipment and assist in all inspection and measuring operations.
The manufacturer shall notify the inspector in ample time for him to arrive at the factory for all inspection, heat treatment and testing. Delay caused by insufficient time allowance on the part of the manufacturer shall not be charged to the purchaser. The amount of advance notice shall be agreed upon by the inspector and the manufacturer at the start of the work.
The manufacturer shall notify the purchaser ten (10) days in advance of starting work in his shop.

Parts subject to being gauged or indicated when set up in a machine shall not be moved from the machine before the inspector has had the opportunity to inspect them.
The manufacturer shall demonstrate that all internals fit correctly by installing them.

7. DRAWINGS AND REPORTS

7.1 PREPARATION OF MANUFACTURER'S DRAWINGS

The manufacturer shall prepare and submit for approval vessel calculations and all shop (or working) drawings, complete in every detail, for the equipment being furnished.

Vessel fabrication shall not be started until written approval has been received from the purchaser.

Vessel assembly drawings shall show the following data, unless otherwise specified in the order:

(a)	Design pressure	bar (g)
(b)	Design temperature	°C
(c)	Maximum operating pressure	bar (g)
(d)	Maximum operating temperature	°C
(e)	Minimum operating temperature	°C
(f)	Design code/construction category	
(g)	Inspection authority	
(h)	Material and weld rod specifications and weld preparation	
(i)	Corrosion allowance	mm
(j)	Hydrostatic test pressure	bar (g)
(k)	Heat treatment sequence and all inspection requirements	
(l)	Location and detail of nameplate and data to be stamped thereon	
(m)	Location of all welded seams and details of all welds	
(n)	Weight of vessel: empty	kg
(o)	Weight of vessel: full of water	kg
(p)	Number of vessels required	
(q)	Finish on flange faces and flange norms	R_a in µm
(r)	Nozzle orientation	

Vessel assembly drawings shall show, in addition to the customary notes, the following notations:

(a) 'Stud bolts and gaskets supplied shall not be used for the hydrostatic test.'

(b) 'All flange faces and other machined surfaces shall be properly protected during fabrication and shipment.'

7.2 DISTRIBUTION AND APPROVAL OF DRAWINGS

As specified in the order.

7.3 VESSEL REPORTS AND DATA SHEETS

Besides specific requirements mentioned in the order, the following reports and data sheets shall be supplied as soon as available.

(a) Certified material report showing intended allocation, heat numbers, chemical analysis and physical properties of the materials used in the fabrication of the vessel and its components.

(b) All cooling curves obtained during fabrication.

(c) All thickness measurements of plates after forming.

(d) All X-ray and ultrasonic data sheets.

(e) Drawing of the vessel(s) indicating the exact location of X-rays and the zero marking.

When each vessel is released for shipment, five copies each of the following completed reports and data sheets, as well as those specified above, shall be supplied by the manufacturer.

These documents shall be collected in data books.

(a) Fabricator's report on test of welding operators and welding procedure qualifications shall be in accordance with the applicable code.

(b) Measurements of the finished vessel made and recorded after post-weld heat treatment. A certified manufacturer's drawing showing dimensional variations will be acceptable.

(c) Photostatic copies of the temperature recording chart obtained during intermediate and final thermal stress-relief. The complete temperature cycle of heating, soaking, and cooling shall be shown.

(d) Photostatic copies of the hydrostatic test pressure gauge chart.

(e) Location, extent and reason of repairs

A 'vessel inspection record drawing' shall be completed for each vessel. This shall be submitted in one transparency and two prints.

NOTE: The manufacturer shall submit calculations, drawings, etc. with S.I. units only.

8. CLEANING AND SHIPPING

After the hydrostatic pressure test the vessel shall be protected against ingress of moisture, dirt, etc. Therefore, all flange faces and other machined surfaces shall be greased and properly protected for shipment.

Each vessel shall be completely sealed and pressurized with dry nitrogen to a pressure of 2 bar. In addition, vessels which are to be transported over the ocean shall be provided with a pressure gauge, valve arrangement and nitrogen cylinder, suitably protected against damage and unwanted nitrogen relief, to permit checking of the nitrogen pressure and refilling if necessary. Vessel flanges not requiring blind flanges shall be provided with plate covers, gaskets and bolting suitable for the nitrogen pressure applied. Flanges provided with permanent blind flanges shall be sealed with a new spiral wound gasket. Test gaskets shall not be re-used.

All bolting, gaskets and other small parts not secured in the vessels shall be suitably and separately packed and identified to avoid loss or damage during shipment. All other parts shall be shipped installed in the vessel.

Vessels shall not be released for shipment without the approval of an inspector authorized by the purchaser.

9. GUARANTEE

The vessel manufacturer shall guarantee each vessel for a period of one year from the time it is put in operation. This guarantee shall apply to the satisfactory operation of vessel components under the specified operating conditions, as well as to material and workmanship.

The purchaser will immediately notify the vessel manufacturer of any defect or faulty operation within the scope of the guarantee. The manufacturer will be given the opportunity to perform the corrective work and replace defective parts. Corrective work shall be done at no cost to the purchaser, within the local job site area and as expeditiously as possible.

Lack of promptness, or refusal to take action after being notified, will result in the purchaser performing the necessary work and back-charging according to regular procedures. Back-charges will include all engineering, travel expenses, subsistence, material and labour involved in obtaining a satisfactory unit.

10. REFERENCES

In this standard specification, reference is made to the following publications.

NOTE: The latest issue of the publications should be used together with any amendments/supplements/ revisions to it. It is particularly important that the effect of revisions to international, national or other standards shall be considered when they are used in conjunction with DEPs and other Shell standards, unless the standard referred to has been prescribed by date.

DEP

Quality of materials (In preparation)	DEP 30.10.02.10-Gen.

STANDARD DRAWING

Skirts, cylindrical and conical	S 20.001

BRITISH STANDARDS

Methods of testing and quality upgrading of ferritic steel plate by ultrasonic methods	BS 5996

Issued by:
British Standard Institution
2 Park Street, London w1A 2BS
England

AMERICAN STANDARDS

Specification for forged or rolled alloy steel pipe, flanges, forged fittings and valves and parts for high temperature service	ASTM A 182
Specification for stainless chromium-nickel steel clad plate, sheet and strip	ASTM A 264
Specification for steel forgings, alloy, for pressure and high temperature parts	ASTM A 336
Methods and Definitions for mechanical testing of steel products	ASTM A 370
Specification for pressure vessel plates, alloy steel, chromium-molybdenum	ASTM A 387
Recommended practice for ultrasonic examination of heavy steel forgings	ASTM A 388
Specification for straight-beam ultrasonic examination of plain and clad steel plates for special applications	ASTM A 578
Practice for magnetic particle examination	ASTM E 709

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American Society for Testing and Materials
1916 Race St., Philadelphia, Pa. 19103, USA

ASME Boiler and Pressure Vessel Code Section VIII, Division 1	
Requirements for post-weld heat treatment Section VIII, Division 2	Part UCS 56

Operation of post-weld heat treatment	Part AF 415
Inspection and radiography	Part AI
Ultrasonic examination	Part AM 203
Non-destructive examination	Appendix 9

Issued by:
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United Engineering Center, 345 East 47th Street
New York, N.Y. 10017, USA

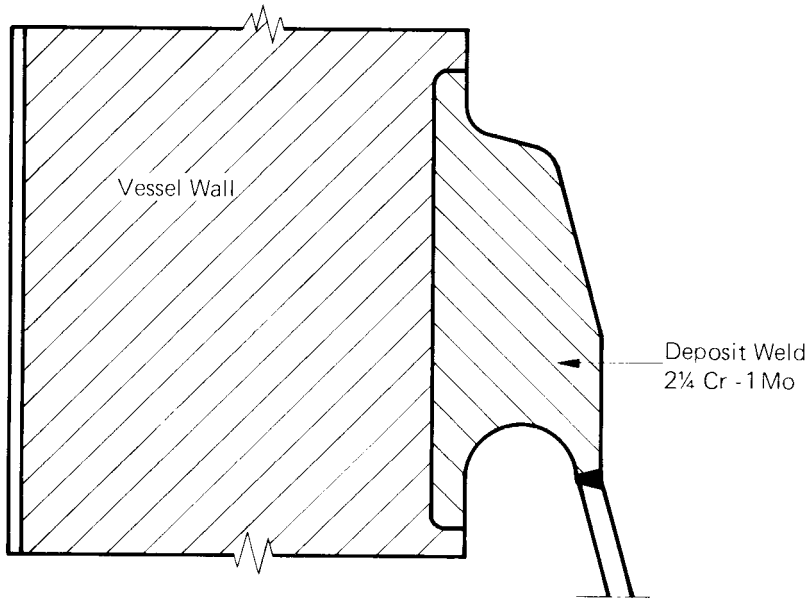
11. APPENDICES

Appendix 1 Example of skirt attachment

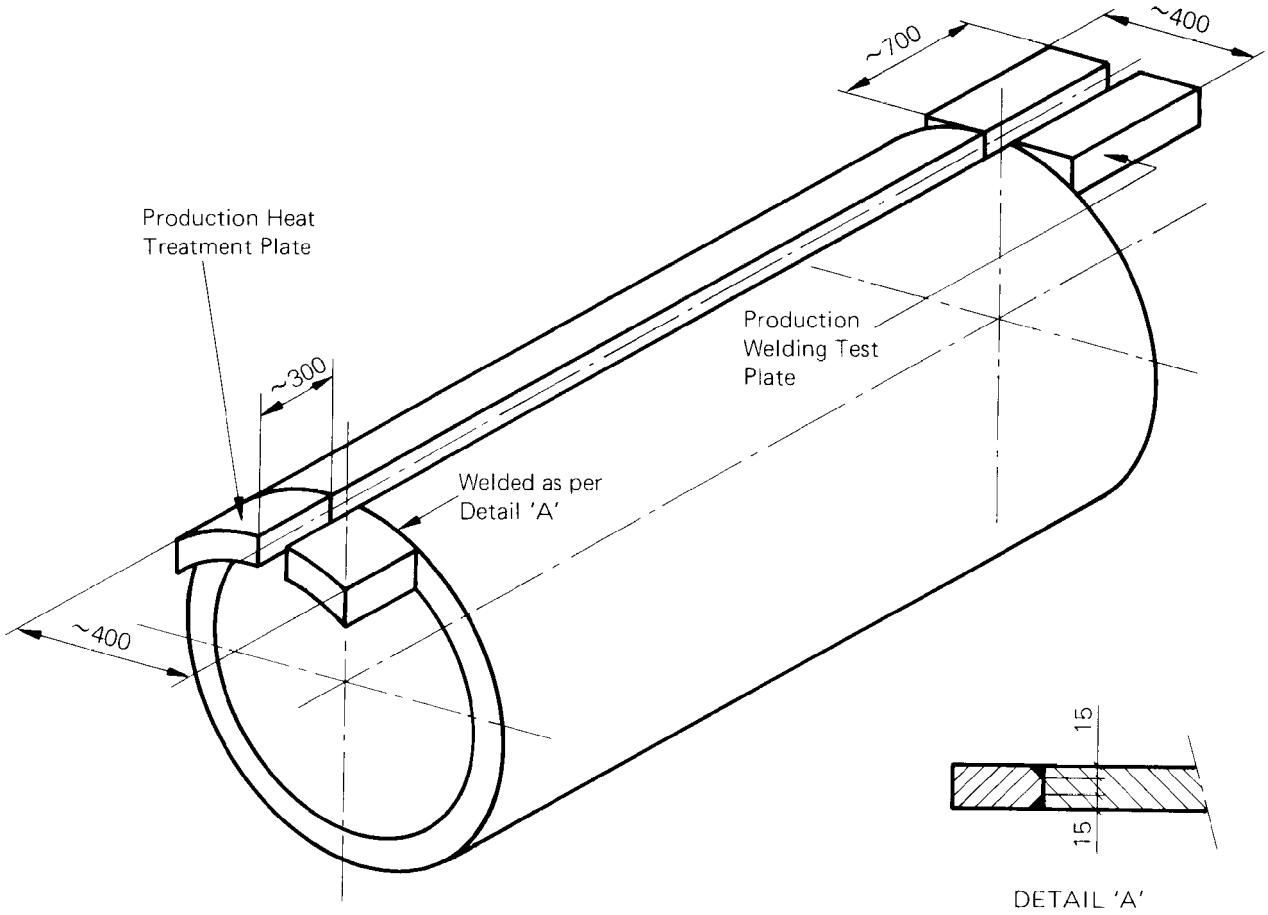
Appendix 2 Position of heat treatment production test plate

Appendix 3 Position of production weld test plate

APPENDIX 1 EXAMPLE OF SKIRT ATTACHMENT



APPENDIX 2 POSITION OF HEAT TREATMENT PRODUCTION TEST PLATE



APPENDIX 3 POSITION OF PRODUCTION WELD TEST PLATE