MANUAL

WELDING OF METALS

DEP 30.10.60.18-Gen.

October 1995

DESIGN AND ENGINEERING PRACTICE

PREFACE

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Shell International Oil Products B.V. (SIOP)
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Shell International Exploration and Production B.V. (SIEP)
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The Hague, The Netherlands,

and other Service Companies.

They are based on the experience acquired during their involvement with the design, construction, operation and maintenance of processing units and facilities, and they are supplemented with the experience of Group Operating companies. Where appropriate they are based on, or reference is made to, national and international standards and codes of practice.

The objective is to set the recommended standard for good design and engineering practice applied by Group companies operating an oil refinery, gas handling installation, chemical plant, oil and gas production facility, or any other such facility, and thereby to achieve maximum technical and economic benefit from standardization.

The information set forth in these publications is provided to users for their consideration and decision to implement. This is of particular importance where DEPs may not cover every requirement or diversity of condition at each locality. The system of DEPs is expected to be sufficiently flexible to allow individual operating companies to adapt the information set forth in DEPs to their own environment and requirements.

When Contractors or Manufacturers/Suppliers use DEPs they shall be solely responsible for the quality of work and the attainment of the required design and engineering standards. In particular, for those requirements not specifically covered, the Principal will expect them to follow those design and engineering practices which will achieve the same level of integrity as reflected in the DEPs. If in doubt, the Contractor or Manufacturer/Supplier shall, without detracting from his own responsibility, consult the Principal or its technical advisor.

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NOTE: In addition to DEP publications there are Standard Specifications and Draft DEPs for Development (DDDs). DDDs generally introduce new procedures or techniques that will probably need updating as further experience develops during their use. The above requirements for distribution and use of DEPs are also applicable to Standard Specifications and DDDs. Standard Specifications and DDDs will gradually be replaced by DEPs.

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APPENDICES

1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for welding of steels and non-ferrous metals. It is a revision of an earlier publication with the same number, dated August 1986.

This DEP does not give detailed technical specifications for weld preparations, welding procedures, etc. For such information use can be made of commercially available systems, such as the software application "WPSelect" published by the Netherlands Welding Institute (see Section 7).

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by SIOP and SIEP, the distribution of this DEP is confined to companies forming part of or managed by the Royal Dutch/Shell Group. It may be distributed to Manufacturers/Suppliers nominated by them (i.e. the distribution code is "F", as defined in DEP 00.00.05.05-Gen.).

This DEP is intended for use in oil refineries, chemical plants, gas plants, exploration and production facilities and supply and marketing installations.

If national and/or local regulations exist in which some of the requirements may be more stringent than in this DEP, 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 document 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 document as closely as possible.

1.3 DEFINITIONS AND ABBREVIATIONS

1.3.1 General definitions

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

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

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.3.2 Specific definitions and abbreviations

Design code:	The code or standard specified by the Principal to which the equipment or piping shall conform.
High-alloy steel:	Stainless steels, 12 Cr and higher
Low-alloy steel:	Steels from 0.5 Mo up to 9Cr-1Mo
	Steels from 0.5 up to 9% Ni
Unalloyed steel:	Carbon manganese steels, including 0.3 and 0.5 Mo steels

AWS	American Welding Society
BS	British Standard
Ceq	Carbon equivalent
DSS	Duplex Stainless Steel
EBW	Electron Beam Welding
ERW	Electric Resistance Welding
ESW	Electro Slag Welding
FCAW	Flux cored Arc Welding
FW	Friction Welding
GMAW	Gas Metal Arc Welding
GMAW P	Pulsed Arc Welding
GMAW S	Short-Circuit Arc Welding
GMAW ST	Spray Transfer
GTAW	Gas Tungsten Arc Welding
GTAW-P	Pulsed Arc Welding
GTAW-HW	Hot Wire Welding
GW	Gravity Welding
HAZ	Heat Affected Zone
LBM	Laser Beam Welding
MT	Magnetic Particle Inspection
NDE	Non Destructive Examination
OFW	Oxy Fuel Gas Welding
PAW	Plasma Arc Welding
PQR	Procedure qualification Record
PT	Liquid Penetrant Inspection
PWHT	Post Weld Heat Treatment
SAW	Sub-merged Arc Welding
SMAW	Shielded Metal Arc Welding
SS	Stainless Steel
UTS	Ultimate Tensile Strength
WPS	Welding Procedure Specification

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents referenced in this DEP are listed in (7).

2. GENERAL WELDING GUIDELINES

2.1 INTRODUCTION

In this section general information is given on qualifications, welding processes and welding methods.

2.2 WELDING QUALIFICATIONS

2.2.1 General

All welding consumables shall have specified or actual mechanical properties equal to or greater than the material being welded, unless otherwise specified.

No production welding shall be carried out until welding procedures and welders are qualified according to the design code and this DEP and approved by the Principal.

2.2.2 Welding procedure qualification

Welding procedures shall be qualified before performance qualification of welders.

Welding procedure specifications together with their qualifications shall be subject to review by the Principal. It is the Manufacturer's responsibility to ensure that welding operations are carried out in accordance with the parameters as specified on the qualified WPS.

Irrespective of the design code, under the following conditions the welding procedure qualification shall be requalified:

Joints

- A change from double sided to single sided welding, but not the converse;
- a decrease in welding groove angle of more than 10 degrees.

Consumables

- Any change of consumable classification;
- any change in consumable brand name when corrosion testing or impact testing is required;
- any change in size of consumable in the root run of single sided welds.

Welding position

- Change in welding direction (vertical up to vertical down welding or vice versa).

2.2.3 Welder performance qualifications

Welder performance qualification testing shall be carried out in accordance with the design code and/or as specified by the Principal.

2.2.4 Welding documentation

Welding Procedure Specification

Qualified procedures in the Manufacturer's own format are acceptable provided the information presented contains all the essential and supplementary essential variables listed in the design code and this DEP.

Welder Qualifications

In order to maintain the validation of approval qualification, a welder performance register should be kept up-to-date by the Manufacturer. This register should at least contain the following data:

- Welder's name and stamp;
- Weld position and X-ray number;
- Data of weld inspection and weld result;
- Materials (base and consumable);
- Configuration data (diameter, wall thickness etc.);
- Reference to welding procedure specification used;
- All other essential variables.

2.2.5 Welding process restrictions

For some welding processes restrictions exist.

2.2.5.1 OFW

OFW may be used only if all of the following are satisfied:

- base material is carbon or carbon-manganese steel;
- UTS < 460 N/mm^2;
- service temperature is above 0 °C;
- pipe diameters < DN 50 mm;
- wall thickness < 5 mm.

2.2.5.2 SAW

Only fully mechanised SAW systems shall be used.

SAW shall not be used for repair welding of pressure vessels, storage tanks or pipelines.

2.2.6 Welding process application

GTAW

GTAW shall be used for all piping materials with a diameter equal to or less than DN 80, except that OFW may be used in accordance with 2.2.5.2.

All GTAW machines shall be equipped with arc starting devices (high frequency, lift arc).

Scratch starting shall not be used.

2.3 SHIELDING GASES FOR WELDING AND CUTTING

2.3.1 General

The prime function of shielding gases is to protect the electrode and the weld pool from the surrounding air. For the various welding processes different shielding gases are used. The gas selection depends on material and process application.

The shielding gases can be divided into inert gas mixtures (argon/helium) and active gas mixtures (CO_2, H_2, O_2). Combinations thereof are also possible.

When shielding gases are utilised, the WPS shall state the composition of the gas, its purity requirements and flow rate.

If gas back-purging is applied, the WPS shall also state the gas used, the flow rate and the method of venting to prevent excessive pressure build-up.

2.3.2 Shielding gases for GTAW

2.3.2.1 Limitations imposed by the GTAW process

For the GTAW process, there shall be any no oxidizing elements such as oxygen in the shielding gas. Such elements will cause oxidation of the tungsten electrode.

2.3.2.2 Reactive metals

For the welding of reactive metals, e.g. Titanium, Tantalum and Zirconium, extremely pure inert gases such as Ar (99.996% vol.) or He (99.996% vol.) shall be used for protection of the arc, weld pool and base metal. These metals require extreme care for shielding to prevent air entrapment into the weld areas. Double shielding, where another shielding gas flow is introduced at the weld area, can be beneficial.

2.3.2.3 Materials susceptible to hydrogen embrittlement and/or hydrogen porosity

Gas compositions for these materials, (e.g. low-alloyed steels, martensitic stainless steels, duplex stainless steels, Al and Al alloys and Cu and Cu alloys), shall be limited to Ar, He or a mixture thereof. A commonly used gas is Argon (99.99% vol.). Pure Helium (99.995% vol.), Helium/Argon (70/30% vol.) or an Argon/Helium (70/30% vol.) mixtures are used if faster welding speeds and more penetration are required.

2.3.2.4 Materials not susceptible to hydrogen embrittlement or hydrogen porosity

Examples of these are austenitic stainless steels, Ni and Ni alloys. Further to the gases mentioned in (2.3.2.3), gas mixtures consisting of Ar and H_2 (95/5 or 90/10% vol.) can also be applied. These gas mixtures will give higher penetration and a lower weld pool viscosity, limiting welding to the downhand position.

2.3.3 Shielding gases for GMAW

2.3.3.1 Limitations imposed by the GMAW process

The filler wires used should be compatible with the type of gas. In case of active gases like CO_2, de-oxidizing elements shall be present in the filler wire.

2.3.3.2 Unalloyed and low-alloyed steel

For the unalloyed and low-alloyed steels, CO_2 gas can be used. Disadvantages are a globular metal transfer and weld spatter (metal losses 15%). Other suitable gases are Ar with additions of CO_2.

The following gas mixtures are available:

Ar/CO_2 (85/15% vol. or 80/20% vol.)

These gases maintain a stable arc and give little spatter. The latter mixture is recommended when deeper penetration is required (e.g. thick plate).

2.3.3.3 High alloyed steels

For heat and corrosion resistant high-alloyed steels, e.g. austenitic stainless steel, Ni and Ni alloys, gas mixtures of Ar with small amounts of O_2 and max. 5% CO_2 can be used. Care must be taken to avoid excessive oxidation of the base/weld metal and carburisation due to CO_2.

Shielding gas mixtures with 99/1, 98/2 and 97/3% vol. Ar/O_2 are available. With increased oxygen content, the viscosity of the weld pool decreases and the burn-off rate of the alloying elements increases. The decreased viscosity produces a smooth weld bead appearance but limits the weld position to the horizontal position only.

To reduce the burn-off rate, an Ar/CO_2 (98/2% vol.) gas mixture can be used for the heat resisting alloys. Also adding 1% vol. H_2 to either Ar/O_2 or Ar/CO_2 will reduce the burn off rate. Addition of hydrogen also increases the arc energy (better penetration, better width/ wall thickness ratio and higher welding speed).

2.3.3.4 Non-ferrous metals

Metals such as Al and Al alloys and Cu and Cu alloys are welded with shielding gases like Ar (99.99% vol.) or a mixture of Ar/He (70/30% vol.). The latter is more often used for metal with a high thermal conductivity coefficient (Cu alloys). When deep penetration (high arc energy) is required, a gas mixture of He/Ar (70/30% vol.) can be used.

2.3.4 Shielding gases for PAW and plasma cutting

2.3.4.1 Plasma welding

For gas applications see (2.3.2).

2.3.4.2 Plasma cutting

Plasma cutting is mainly used for high-alloyed steels. Depending on the material quality to be cut, air or a gas mixture of Ar/H_2 is used in the combinations 85/15, 80/20 and 65/35% vol. The higher the H_2 content the higher the arc energy, resulting in higher cutting speeds and/or cutting thicker plates.

2.3.5 Backing gases for welding

When welding the root and the first pass, the backside of the weld can be protected to prevent oxidation. The following backing gas applications can be distinguished.

Material	Gas composition
Stainless steels	N_2/H_2 (95%/5% - 85%/15%) or Ar (99.99%)
Low-alloy Cr-Mo steels	N_2 or Ar (99.99%)
Martensitic stainless steels	N_2 or Ar (99.99%)
Non-ferrous alloys	Ar (99.995%)
Reactive metals Ti, Ta and Zr	Ar (99.996%)
Duplex Stainless steels	Ar (99.99%) or Ar/N_2 (98/2%)

2.4 WELDING CONSUMABLES

2.4.1 Consumable approval

Welding consumables shall be purchased from manufacturers who are acknowledged by bodies which independently test consumables, e.g. Controlas, Lloyd's Register of Shipping, American Bureau of Shipping and Det Norske Veritas.

All welding consumables shall have specified tensile, impact and chemical analyses values under their various international classifications.

Consumables not so approved shall be subject to approval by the Principal.

Welding consumables for low temperature service shall also comply with the design code and DEP 30.10.02.31-Gen.

All consumables shall be shown on the WPS by their AWS classification or BS designation, dependent on the design code. Welding fluxes shall be specified by manufacturer and type.

2.4.2 Consumable storage

Welding consumables shall be stored with care in accordance with manufacturers instructions under clean, dry conditions in their original unopened packing.

Flux-coated electrodes (particularly basic low-hydrogen) and SAW fluxes shall be stored in heated storage areas under controlled temperature/humidity conditions.

Storage and baking of welding consumables shall be carried out in different ovens. Ovens shall be heated by electrical means and shall have automatic heat controls and visible temperature indication.

The storage, baking, issue and return of welding consumables shall be controlled by procedures with documented records.

Basic low-hydrogen electrodes and fluxes shall be baked in accordance with the manufacturers' instructions and shall give a weld metal deposit with a diffusible hydrogen content which shall not exceed 10 ml/100 g weld metal.

Extra moisture resistant (EMR) consumables with a diffusible hydrogen content of less than 5 ml/100 g can be used without preheated storage for a period of maximum 8 hrs.

The level of hydrogen can be tested using the procedure in BS 6693 part 1 to 5 if there is any doubt as to the welding consumable control level or if extra moisture resistance needs to be confirmed.

No electrodes shall be left lying about the site or in workshops. Electrodes so left shall be scrapped, as shall electrodes which have damaged flux coatings.

Submerged arc flux shall be supplied clearly identified in moisture-proof containers and shall be stored in a dry location at a temperature above 20 °C. The identification shall state manufacturer, grade and batch number.

Submerged arc, gas metal arc and flux-cored wire shall be clearly identified and shall be stored in a dry location at a temperature above 20 °C. The identification shall state manufacturer, grade and batch number. Unidentifiable and/or rusty wire shall not be used.

Submerged arc, gas metal arc and flux-cored arc consumables shall be withdrawn from store only when required for immediate use. Unused consumables shall be returned to store on completion of the welding operation. Batch numbers shall be recorded on issue. After issue from storage, agglomerated fluxes shall be held in a heated silo at 70 °C.

Submerged arc flux may be recycled but shall be free from fused flux, slag particles, mill scale, dirt or other foreign matter. Before re-use, the flux shall be rebaked in accordance with the Manufacturer's instructions.

2.5 WELDING

2.5.1 Weld preparation

The weld preparation shall be in accordance with the design code and as specified by the Principal.

Thermal cutting may be used for un-alloyed and low-alloy steels.
Plasma cutting shall be used for high-alloy steels and clad steels.

For plates less than 25 mm thick, cold shearing may be used.

For plates between 11 and 25 mm thick, the cold sheared cut edges should be dressed back at least 2 mm by machining or grinding. Sheared plates 10 mm and less in thickness need not be dressed back.

Thermally-cut surface edges of low alloy and high alloy steels shall be dressed back approximately 2 mm by machining or grinding to remove notches and scale.

For Ni-steels used for low temperature application, the edge preparation shall be done by machining or grinding. Flame cutting may be used followed by 4 mm grinding or machining. Cold shearing shall not be used.

Two-sided welding shall be applied whenever possible.

Permanent backing strips shall not be used unless specified otherwise for specific applications.

Temporary backing devices (ceramics, fluxes, copper backing strips etc.) may be used provided that the chemical composition of the weld metal is not influenced by the backing strip. The strip shall be removed without damage to the surrounding material. The areas involved shall be ground flush and cleaned after removal.

Welds of low-alloy ferritic steels shall be inspected by MPI after the removal of the metallic backing strips or other temporary weldments, with acceptance criteria in accordance with the design code.

2.5.2 Weld fit-up

Weld fit-up shall comply with the design code.

All surfaces to be welded shall be thoroughly cleaned from oxide, scale, oil or other foreign matter and be dry. The cleaned surface shall extend at least 25 mm beyond the substrate surface touched by the arc.

Tack welding shall be carried out by qualified welders in accordance with the same requirements and parameters as for the root pass of the base material.

Temporary tack welds shall not touch the root gap or the root face. Tack welding with small pieces of round bar in the groove will produce this effect. Temporary tack welds shall be removed by grinding or chipping and the area ground smooth without reduction of wall thickness, followed by MT or PT inspection to confirm the absence of linear indications.

Non welded fit-up clamps shall be used for alignment of all pipe, pipeline and equipment work.

Weld-on fit-up devices may be used with the approval of the Principal on structural steel work if the UTS of the material is below 460 N/mm^2. They shall be attached in accordance with the qualified weld procedure specification and shall be removed by chipping/grinding without damage or reduction in wall thickness of base material. Such areas shall be ground smooth and examined by MT or PT to confirm the absence of linear indications.

2.5.3 Welding conditions

No welding shall be carried out when the parts to be welded are wet. No welding shall be performed unless the welder and the work are properly protected from wind.

When the base metal temperature is below 5 °C, both sides of the weld preparation shall be preheated to a temperature of approximately 50 °C or the preheat temperature prescribed in the WPS, whichever is higher.

2.5.4 Weld application

Arc strikes shall be situated in the fusion path. When interruption in welding takes place, a proper restart procedure shall be used, ensuring full fusion with the previously deposited weld metal.

Irrespective of the base material, root runs shall be made without interruption other than for changing electrodes or to allow the welder to reposition himself. Welds shall not be allowed to cool until at least half the wall thickness has been welded.

Thorough inter-run cleaning and slag removal shall be carried out.

Back-chipping, or gouging and grinding, shall be carried out thoroughly to sound metal before deposition of subsequent layers. For very stringent or critical applications, intermediate NDE may be required (as specified by the Principal).

2.5.5 Liquid Metal Embrittlement (LME)

LME is the reduction in elongation (to failure) that can occur when normally ductile metals or alloys are stressed while in contact with liquid metals. A major area of concern is the presence of zinc on austenitic stainless steels and high nickel alloys.

During fabrication and heat treatment of stainless steel equipment, contamination of the stainless steel with zinc from paint or zinc-coated equipment must be avoided. The use of galvanized wires to fix thermocouples during heat treatment has been known to cause embrittlement and cracking.

In the welding of stainless steel, cracking can occur if zinc is present in the region of the weld. Galvanized steel or zinc containing paints are the most likely source of trouble, and equipment to be welded should be made completely free from zinc before any welding is undertaken.

Care shall be taken when flame cutting or welding galvanized parts to ensure that no zinc droplets can fall onto austenitic stainless steel. If this should nevertheless occur, removal of these zinc droplets shall be undertaken before any welding takes place .

In the construction and fabrication of austenitic stainless steel equipment, piping, etc., where welding and heat treatment is to be carried out, galvanized or other zinc coatings should not be allowed to contact the hot steel. Where the presence of zinc is suspected, inspections should be undertaken prior to heat treatment to ensure that the materials susceptible to LME are not contaminated with zinc.

3. HARDNESS REQUIREMENTS

The following hardness requirements for base material, heat-affected-zone and weld metal are applicable:

- 248 HV10 maximum for ferritic metals in process services.
- 290 HV10 maximum for ferritic materials in utility service (steam, air, water).
- 290 HV10 maximum for 9% Ni steels in the as-welded condition and for 9Cr-1Mo modified steel (P91, T91) in the PWHT condition.
- 325 HV10 maximum for structural steels.

The weldability and hardness of unalloyed steels depends on the carbon content and the carbon equivalent (Ceq).

Good weldability and compliance with the hardness requirements can be obtained without the necessity of a PWHT (unless required by the design code) if the following heat analyses are met:

$C \leq 0.23$ for plate materials

$C \leq 0.25$ for forgings and castings

$Ceq < 0.45$

Ceq is established by the following formula:

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

4. PREHEAT AND POST-WELD HEAT TREATMENT

4.1 GENERAL REQUIREMENTS

Heat treatment shall be carried out in accordance with a qualified heat treatment procedure specification based on the requirements stated in the design code, requisition or purchase order. The heat treatment procedure shall be reviewed and approved by the Principal.

Heat treatments may be carried out either full-body or locally, depending on:

- type of heat treatment;
- material composition of work piece;
- number and sizes of work piece;
- configuration of work piece;
- availability and cost of energy;
- required accuracy of heat treatment;
- design code requirement.

4.2 PREHEAT REQUIREMENTS

Preheating of the parent metal prior to any welding, tack welding and thermal cutting may be necessary to avoid cold cracking of certain ferritic steels in the weld and HAZ.

Preheating could also be required for welding of non-ferrous materials to remove moisture or to prevent hot cracking.

The preheat temperatures shall be in accordance with the design code.

Where necessary, the preheat temperature shall be calculated (in accordance with either BS 5135 or ASME Section VIII Div. 2 non-mandatory Appendix D, or ANSI/ASME B31.3) to suit particular combinations of welding process, heat input, metal composition, welding consumables and plate thickness.

For preheating temperatures below 200 °C, fuel gas/air burner systems, high-velocity gas/oil burners or infra-red radiators may be employed (either locally or in a furnace), or electric resistance, induction heating or infra-red radiators may be employed. For cast iron see (5.10).

For preheating temperatures ≥ 200 °C, electric resistance or induction heating should be used but infra-red radiators may be used.

For piping welds made in the shop, electrical heating should be used, but ring torches may be used if burning sulphur-free fuel.

For piping welds made in the field, the following methods of preheating shall be applied:

- pipe diameter ≤ 250 mm, heating by appropriate torches is allowed (sulphur-free fuel);
- pipe diameter > 250 mm, electrical heating or heating by means of infra-red or ringburners (sulphur-free fuel) is required.

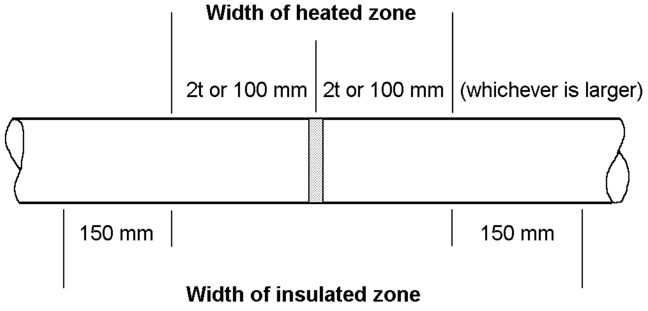
Specifically designed heating nozzles and torches shall be used; cutting torches shall not be used.

Oxy-acetylene preheating shall not be applied.

An even temperature distribution shall be achieved.

Temperature control can be carried out with temperature sensitive crayons, digital pyrometers, contact thermometers or calibrated thermocouples.

The width of the heated zone shall be as shown below. If electric resistance elements are used, insulation shall be applied with a width as shown below.
t = nominal wall thickness of the pipe.



The weld shall be completed before the preheat temperature is lowered, except that intermediate lowering of preheat temperature is permitted for unalloyed steels if at least 50% of the weld has been completed. The joint shall be cooled under insulation. Preheating shall be restored to the specified temperature and maintained for 30 minutes before welding is recommenced.

4.3 POST-WELD HEAT TREATMENT (PWHT)

PWHT temperature ranges and holding times for various materials shall be in accordance with the design code. The following rules also apply:

1. PWHT may be required for Ceq ≥ 0.45 or C ≥ 0.23 depending on the application and the hardness requirements.
2. For optimum high temperature creep properties, the lower side of the temperature range is normally used.
3. For 0.3-0.5% Mo steels in hydrogen service, PWHT is required irrespective of the wall thickness.
4. For maximum softening the higher side of the temperature ranges is used.

The welding procedure qualification tests shall determine whether the temperature range and holding times are adequate to meet the requirements.

NOTES:
a) The carbon content of Cr-Mo steels influences the choice of the PWHT temperature. The higher specified temperature shall be used to obtain the required hardness for materials with a higher carbon content.

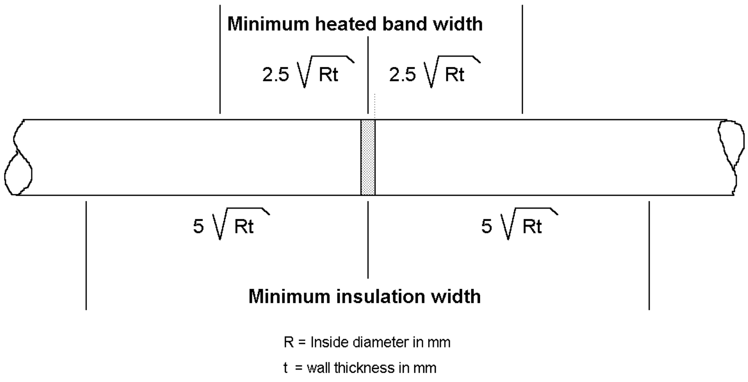
b) For quenched/normalized and tempered steels, the PWHT temperature shall be such to avoid an unacceptable decrease of mechanical properties of the parent material, PWHT temperature shall be at least 20 °C below the tempering temperature.

c) In case of dissimilar metals the PWHT temperature shall be approved by the Principal.

No welding or heating shall be carried out after final PWHT. NDE for acceptance purposes shall be carried out after final PWHT.

Exothermic kits shall not be used.

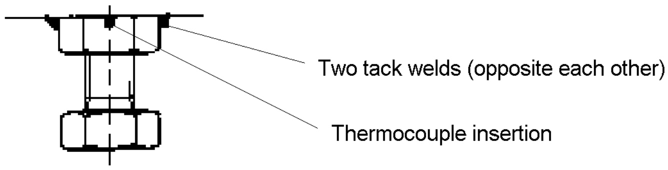
If PWHT is applied locally, the minimum heated band width and the minimum insulation width shall be as shown below:



4.4 THERMOCOUPLES

Thermocouple attachments should be:

- capacity discharge connection, or
- nut and bolt construction (as shown below)



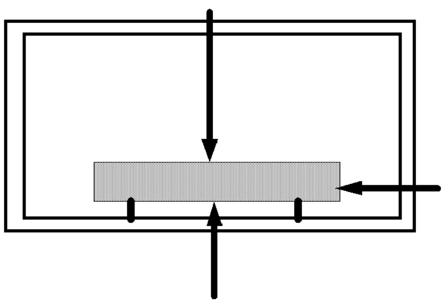
If the latter method is used, the materials should be of a compatible composition. The weld metal shall be removed by careful dressing followed by MT or PT examination after PWHT to confirm absence of linear indications.

Other types of thermocouple attachment may be used provided it is demonstrated that the same temperature reading is obtained when compared with a capacity discharge or a bolt/nut connection.

All thermocouple attachments shall be adequately insulated to avoid temperature misreading caused by the effect of radiation.

The number and positions of the thermocouples shall be in accordance with the design code, but at least as described below:

- For full body heat treatment, at least 3 thermocouples shall be directly welded on the work piece, as indicated in the sketch:

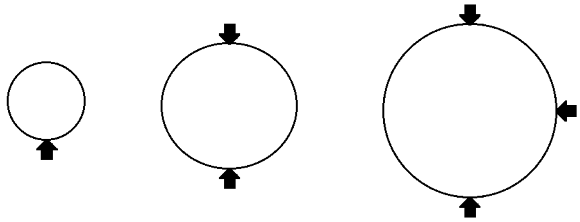


NOTE: For a hollow configuration, there shall be one additional thermocouple on the inside .

For local heat treatment of pipe the number of thermocouples shall be:

1 for pipe diameter < DN 50
2 for pipe diameter from DN 50 to DN 250
3 for pipe diameter > DN 250

The thermocouples shall be positioned as shown in the sketch:



D ≤ 50   50 < D < 250   D ≥ 250

For local heat treatment of equipment, the number and positions of thermocouples shall be determined in consultation with the Principal.

4.5 REPAIR/MODIFICATIONS

4.5.1 Vessels

For repair or modification to pressure vessels originally supplied in the PWHT condition, a complete PWHT of the vessel on completion of repair/modification may not be necessary.

"Local" PWHT can be executed under the following conditions if allowed by the design code:

A fully circumferential band shall be heated with a minimum width as follows:

$$\text{minimum band width} = \text{repair width} + 5\sqrt{Rt}$$

The minimum insulation width shall be as follows:

$$\text{minimum insulation width} = \text{repair width} + 10\sqrt{Rt}$$

Both bands shall be equally distanced from centre of repair.

4.5.2 Repair welding of equipment that has been in hydrogen, sour or HF (hydrogen fluoride) service

Repairs to be carried out on carbon steel or Cr-Mo equipment which has already been used in service shall be treated as follows:

The area to be repaired shall be preheated in accordance with temperatures and holding times as specified in (Table 5.4.1) to remove sufficient hydrogen from the area to avoid possible cold cracking. After this heat treatment, repair welding and PWHT can be carried out as described in (Section 4) and (Section 5.3).

NOTE: Sour service is defined in DEP 31.22.10.32-Gen. and DEP 31.22.20.31-Gen.

5. GUIDELINES FOR THE WELDING OF SPECIFIC MATERIALS

5.1 CARBON AND CARBON-MANGANESE STEELS

5.1.1 General

Carbon and carbon-manganese steels are generally used as construction material for pressure vessels, piping, supports, and building structures.

The readily weldable low-carbon steels are applied for most cases.

The weldability of ferritic steels depends on the carbon content and the carbon equivalent (Ceq).

Good weldability without the necessity of PWHT is obtained when the following product analyses are met:

1. $C \leq 0.23$ for plate materials
2. $C \leq 0.25$ for forgings and castings
3. $Ceq < 0.45$

The weld quality is directly related to the carbon content and Ceq. If the values are beyond the above limits, more precautions shall be taken. The main problems are hardening in the weld metal and HAZ, with a high risk of hydrogen cold cracking.

If the specifications for carbon content and Ceq are not met, a PWHT may be required to comply with the design code.

5.1.2 Carbon steels with UTS < 460 N/mm^2

Generally no special precautions are required for welding. Suitable shielded metal arc electrodes are rutile, cellulosic or basic low-hydrogen types. For wall thicknesses above 25 mm, basic low-hydrogen electrodes shall be applied.

5.1.3 Carbon and carbon-manganese steels with UTS ≥ 460 N/mm^2

In most cases these do not meet the C and Ceq requirements, and approval from the Principal is required for their use.

If they are considered acceptable, special precautions shall be taken to avoid unacceptable hardening and cold cracking. Basic low-hydrogen welding consumables shall be used, and preheating shall be performed in accordance with the design code.

In most cases, a PWHT is required to reduce the hardness and to restore the ductility in the HAZ.

5.1.4 Fine-grained carbon and low nickel alloy steels

These steels have improved toughness properties. The fine grained carbon steels are divided into two tensile strength groups:

- UTS < 460 N/mm^2
- UTS ≥ 460 N/mm^2.

The lower strength steels are readily weldable, since the C and Ceq requirements are generally met. Basic low-hydrogen electrodes matching the mechanical properties shall be used.

It may be required to apply preheating to ensure that no cracking will occur in the HAZ. The preheat temperature shall be in accordance with the design code.

However, for the higher strength steels precautions are required to avoid hydrogen cold cracking and hardening. Basic low-hydrogen electrodes shall be used. Preheating between 100 and 150 °C in accordance with the design code shall be performed for wall thicknesses above 25 mm.

It should be noted that in sour service (see NACE MR0175) the maximum nickel composition in the weld metal shall be 1.0%.

5.2 5% AND 9% NICKEL STEELS

5.2.1 General

5% and 9% Ni steels are used in cryogenic services, usually below -100 °C.

The mechanical properties of these steels are obtained by a complex thermal treatment. This includes quenching and tempering or double normalizing and tempering. The thermal cycle during welding may have a negative effect on the mechanical properties of the HAZ.

5.2.2 Welding consumables

5% and 9% Ni steels shall be welded with consumables which contain 60-70% Ni and 8-10% Mo (e.g. Incoweld A/B, Inconel 625, Inconel 182 or Inconel 112).

Consumables with 40% Ni, with a thermal expansion coefficient similar to that of the base material, may be used for 5% Ni steel in services colder than -120 °C.

Austenitic stainless steel consumables shall not be used.

Alternating current shall be used with SMAW, since direct current may cause magnetic arc blow problems and consequent lack of fusion.

5.2.3 Weld preparation

High-nickel welding consumables have a higher viscosity and a lower melting point than the 5% or 9% Ni-steel base metal.

Weld preparations should have a greater included angle than for carbon steel, to minimize the risk of lack of fusion defects due to the low fluidity of the weld metal.

For the complete fusion of a subsequent weld run, all convex weld beads of the previous runs shall be ground flush.

To remove the crater and to avoid hot cracking, the end of each electrode run shall be removed by grinding.

To avoid excessive porosity the backward manipulation shall be as short as possible.

Back-welding shall be applied if access permits.

5.2.4 Preheating

In order to remove moisture, preheating at maximum 70 °C may be applied if the wall thickness is above 20 mm.

5.2.5 Welding procedure qualification

Welding procedure qualifications shall be made for the combination of the highest heat input and the smallest plate thickness within the qualification range.

The heat input to plate thickness ratio (joules/mm) shall be limited to 0.1 maximum for Incoweld A/B and Inconel 182. The ratio shall be limited to 0.2 maximum for Mo-containing high Ni weld metals.

5.2.6 Post-weld heat treatment

The range for PWHT shall in accordance with the steel Manufacturer's recommendations.

The PWHT temperature shall always be at least 20 °C below the tempering temperature to avoid deterioration of the mechanical (particularly the toughness) properties of the parent material.

5.3 0.3% AND 0.5% MOLYBDENUM STEELS

5.3.1 General

The weldability of 0.3-0.5% Mo steels depends on the carbon content and the carbon equivalent (Ceq), see section 3.

For preheat and PWHT requirements see section 4.

5.3.2 0.3% Mo steel

0.3% Mo steel shall be welded with basic low-hydrogen consumables depositing 0.5% Mo.

5.3.3 0.5% Mo steel

0.5% Mo steel shall be welded with matching (for SMAW, basic low-hydrogen) consumables.

The welded joints shall be cooled down under insulation from the preheat to ambient temperature.

5.4 LOW-ALLOY CHROMIUM-MOLYBDENUM STEELS

5.4.1 General

Weldability is related to the carbon, chromium and molybdenum content, i.e. the higher the content of these elements, the more precautions shall be taken to avoid hydrogen cracking.

Preheating, interpass temperature, post-heating and PWHT shall be strictly controlled.

For thicknesses below 10 mm, the cooling from preheating to ambient temperature shall be done under an insulating cover.

For thicknesses between 10 and 30 mm intermediate post weld heating shall be applied after welding, prior to cooling to ambient temperature, in accordance with Table 5.4.1, unless a full PWHT is carried out immediately.

TABLE 5.4.1 Post-heating holding time in hours

Plate thickness (mm)	150 °C	200 °C	250 °C	300 °C
10 to 20	6	3	2	1.5
20 to 30	10	7	5	3

For sections thicker than 30 mm an intermediate PWHT at 600-620 °C shall be carried out immediately after welding without cooling down to the ambient temperature.

Final PWHT shall always be carried out.

The PWHT temperature for tempered grades shall be at least 20 °C below the tempering temperature.

Reference shall be made to W-6-1/2/3 with respect to material, welding and fabrication requirements.

5.4.2 1Cr-0.5Mo and 1.25Cr-0.5Mo

These materials shall be welded with low-hydrogen consumables which deposit a matching chemical composition. These materials are susceptible to cracking caused by hydrogen and to a hardened microstructure. Preheating between 100 and 150 °C shall be applied. To minimize air hardening after welding, cooling down to ambient temperature shall be done under insulation.

5.4.3 2.25Cr-1Mo and 3Cr-1Mo

These materials are highly susceptible to cracking, therefore extreme care shall be taken when welding is carried out.

Only basic low-hydrogen consumables which deposit a matching chemical composition weld metal shall be used.

Alloy additions to weld metal shall take place only via the filler wire. Alloy addition shall not be via flux or coating, except to compensate for alloy burn-off during welding.

The weld metal shall be checked prior to use for the specified amounts of Cr and Mo.

Preheating shall be carried out regardless of wall thickness. Interpass temperature shall not drop below the preheat temperature during welding. For PWHT and intermediate PWHT see (5.3.1).

5.4.4 5Cr-0.5Mo, 9Cr-1Mo and 9Cr-1Mo modified (T91, P91)

Basic low-hydrogen consumables with matching chemical composition shall be used.

These materials are susceptible to cracking by hydrogen and to a hardened microstructure.

Due to the higher Cr content they are more liable to air-hardening, and the preheat temperature shall be 200-250 °C.

9Cr-1Mo modified (P91, T91) differs from standard 9Cr-1Mo steel in that alloy additions are made (vanadium, nitrogen, nickel, niobium) to enhance its properties. Weldability is comparable with 9Cr-1Mo steels.

NOTE: Due to the difference in chemical composition, the order/requisition should clearly specifiy which consumable type is needed (e.g. state explicitly whether 9Cr-1Mo or 9Cr-1Mo modified consumables are required).

5.5 STAINLESS STEELS

5.5.1 General

Stainless steels can be divided into four groups:

- martensitic SS
- ferritic SS
- austenitic SS
- austenitic/ferritic (duplex) SS.

Based on the application, stainless steels can also be divided into:

- corrosion-resistant SS
- creep and oxidation-resistant SS
- low-temperature-resistant SS.

Consequently the rules for welding of stainless steels depend not only on the microstructure but also on the required application.

Stainless steels shall not come in contact with unalloyed or low alloy steels. Fabrication of stainless steels shall be done separately in a work area and with tools only to be used for the fabrication of stainless steels.

Austenitic stainless steels are susceptible to hot cracking caused by the high coefficient of thermal expension of the material in combination with the high affinity of nickel to the pick-up of impurities like sulphur, forming low melting nickel sulphides. To avoid this problem a high level of cleanliness is required when welding austenitic stainless steels.

5.5.2 Martensitic and ferritic stainless steel

5.5.2.1 Application

The martensitic and ferritic SS are not generally used as material for welded constructions, since they often give problems during fabrication, welding and heat treatment.

Examples of applications are:

- strip lining or cladding of pressure vessels to resist sulphur corrosion;
- internals of valves;
- tray decks;
- castings for pumps;
- strip lining or cladding of pumps.

5.5.2.2 Welding

The main problem with welding of martensitic and ferritic SS is the susceptibility to hydrogen induced cracking (cold cracking) of the weld metal and the HAZ due to the formation of martensite with high hardness.

In most cases, martensitic and ferritic SS are welded with an austenitic type of weld metal. The martensite formation is then restricted to the HAZ. The hardness of the martensite in the HAZ can be reduced by selecting a material with a lower carbon content.

To prevent cold cracking in the HAZ of welds in thick sections of e.g. pumps/valves casings, the following measures shall be taken:

- preheat to 200-250 °C;
- weld with austenitic basic coated low-hydrogen type of consumables;
- maintain the interpass temperature at 200-300 °C during the welding operations;
- post-heat at 200-250 °C, cooling to 100 °C, immediately followed by a heat treatment at 700-790 °C to change the martensite into carbides and ferrite.

The ductility of the ferritic SS in the HAZ may be poor due to grain growth and/or formation of carbo-nitrides. An annealing heat treatment at 950-1060 °C and air cooling will often improve the ductility to an acceptable level.

5.5.3 Austenitic stainless steel

5.5.3.1 Welding

Selection of the welding consumables depends on the type of austenitic SS and the intended service. To prevent any problems during fabrication, heat treatment, welding and service, the following rules shall apply:

- Tack welds shall be made at small intervals.
- Heat input per weld run should be low to avoid too high an interpass temperature and overheating of the weld area.
- Cleanliness is very important; special attention shall be paid to the weld area to avoid carbon pick-up, hardening and hot cracking.
- For GMAW or GTAW welding, backing gas shall be applied to prevent oxidation of the HAZ and weld.
- After heavy oxidation of the weld and HAZ, the corrosion resistance can be restored by pickling and passivation or by chemical cleaning followed by passivation.
- For most applications a weld consumable is used with a low susceptibility to hot cracking in the weld metal, e.g. a weld metal with 3-8% ferrite.
- To prevent sensitization and weld decay at the grain boundaries, the carbon content for corrosive service is kept below 0.03% C or the parent metal is stabilized with Nb or Ti.

General service:

The SS selected are in most cases AISI 304, 321 or 347. Sometimes AISI 316 is applied.

The Cr and Ni content shall produce a weld metal with 3-8% ferrite. Austenitic SS stabilized with Nb or Ti are welded with consumables stabilized with Nb as Titanium will oxidize in the welding arc. The ferrite content can be measured with a ferrite-scope.

(Severe) corrosive service:

The SS selected are the low-carbon types, e.g. AISI 304L/316L, and/or the stabilized types, e.g. AISI 321, 347, 316Ti, 316Nb.

The selection of welding consumables shall be related to the intended corrosive service and/or fabrication procedures. In practice this means that either low-carbon (C < 0.03%) or stabilized SS filler material is to be used. The corrosion resistance of the weld metal will improve if a lower percentage of ferrite is specified.

However, with too low ferrite content the weld metal is prone to hot cracking while too high ferrite content promotes the formation of sigma phase during heat treatment. An amount of 3-8% ferrite should be specified. Special types of consumables shall be selected with a basic type of coating or flux.

For severe corrosive service austenitic SS may be specified with an increased Mo content, e.g. 18Cr-12Ni-4Mo (AISI 317).

The structural stability of AISI 317 is much less at elevated temperatures than e.g. AISI 316. The heat input shall be restricted to prevent the formation of ferrite/sigma phase in the HAZ during welding. The interpass temperature shall be kept below 150 °C.

The welding consumables shall have a matching chemical composition with a ferrite content of maximum 5%, hence high Ni and N.

Moderate to high-temperature service:

The selected SS are AISI 304Mod, 304H and 321H.

For castings, AISI 347H material is sometimes used. The SS shall be welded with consumables which match the main elements Cr, Ni, Mo and C.

The carbon content of the weld metal shall be minimum 0.04% C to obtain ample creep properties. The carbon content for the non-stabilized SS shall be kept below 0.06% C to reduce any intercrystalline attack during idle periods of the construction and embrittlement in service.

The normal types of consumables used for the welding of corrosion-resistant austenitic SS cannot be used since the carbon content is too low in the weld metal. Filler material shall meet the AISI 308H requirements. The ferrite content shall be between 3-8%.

High-temperature service:

For high-temperature service, 25Cr-12Ni or 25Cr-20Ni, SS may be selected. For severe creep conditions cast alloys with an increased carbon content are generally used.

To obtain the required creep properties, the composition of the welding consumables shall match the base material. The weld metal obtained is often fully austenitic and care shall be taken to avoid the formation of hot cracks.

Low-temperature service:

The SS grades selected for low-temperature service are the same as for general service.

Weld metals containing Nb should not be used for service temperatures below -105 °C, since the impact requirements might not be fulfilled.

The impact properties of the austenitic weld metal may be impaired by a large amount of ferrite (>8%) or the formation of martensite from metastable austenite at -196 °C. The ferrite content shall therefore be limited to maximum 8%.

5.5.4 Welding of Duplex Stainless Steels (DSS)

Welding may have a significant adverse effect on corrosion behaviour of these alloys; they can show a major change in the ferritic-austenitic balance at welds and HAZ.

The majority of problems arising from poor toughness and corrosion resistance that have lead to failures and difficulties in fabrication in DSS have been related to the quality of welding, incorrect selection of consumables, inadequate welding procedures for all geometries being considered, lack of cleanliness after welding or inadequate heat treatment.

The aim when welding DSS is to produce a weld metal and HAZ equal in toughness and corrosion resistance to the base metal. The high nitrogen contents of modern alloys help in this respect by increasing the austenite formation in the HAZ during cooling. Filler metals with higher nickel content than the base material should be used to ensure that the weld structure is comparable in properties with the base metal; matching nickel contents produce too high ferrite contents in the weld.

In DSS, too high or too low heat input produces loss of toughness in the weldment. Too low heat input might not allow sufficient time for adequate austenite formation. Too high a heat input, or the accumulation of total exposure time in the critical temperature range by the HAZ of a multipass weld, could lead to the formation of detrimental intermetallic phases. Control of interpass temperature is essential and should be below 150 °C.

Welding procedure qualification tests shall be conducted to verify the WPS and shall simulate the conditions and materials to be used for production welding

The PQR shall also include impact testing (with acceptance criteria appropriate to the application) as well as ferrite determination. The acceptable range for ferrite is 35 to 55%, preferably at the lower side of this range.

Ferrite content shall be determined by microscopic ferrite count analysis.

DSS can be welded using most welding processes, but for field welding where access to the weld is limited to one side only (backwelding not possible), GTAW shall be used with a hydrogen free shielding gas (e.g. argon) to avoid possible cracking and embrittlement of the weld.

SMAW consumables shall be handled as low-hydrogen consumables (2.4.2) to avoid hydrogen cracking in the ferritic phase of DSS.

As current DSS contain appreciable amounts of nitrogen, both as an austenite former and to enhance pitting resistance, control of this element is essential. Diffusion from the HAZ to weld metal and/or loss of nitrogen from the weld pool may occur. This can be reduced or prevented by use of argon/nitrogen (max. 2.0 % nitrogen) shielding gas.

During welding, DSS shall be protected from oxidation by providing a shielding purge on the inside with the same gas composition as the shielding gas used for welding. The backing gas purge shall replace all air. No welding shall start until the oxygen content has dropped to below 50 ml/m^3. During the root run there may be a surge when the welding is started and welding shall be stopped if this surge goes higher than 500 ml/m^3.This shall be measured with an oxygen analyser, capable of measuring oxygen contents between 0 and 1000 ml/m^3.

The root side shall be subjected to visual inspection to determine the level of oxidation prior to any destructive testing.

Welds shall have no burn marks (which can result when using SMAW or can be caused by improper back-purging when using GTAW). The weld appearance should be shiny but a small degree of grey oxidation on and near the weld is acceptable. The acceptable degree of oxidation is difficult to quantify but, in case of doubt a materials engineer should be consulted.

NOTE: Colour photographs, showing acceptable and unacceptable discolouration, are available in SIOP.

5.6 NICKEL AND NICKEL ALLOYS

5.6.1 General

Nickel and nickel alloys are selected based on their ability:

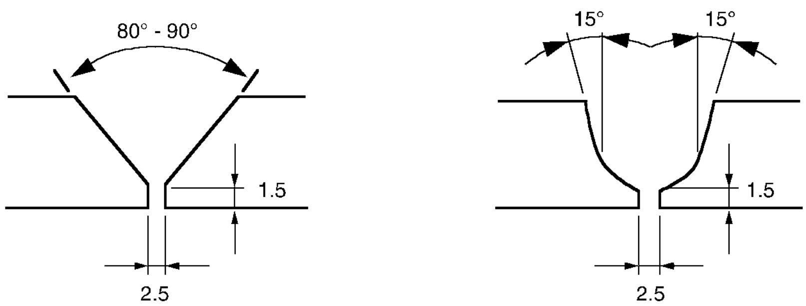
- to resist electrochemical corrosion and/or stress corrosion;
- to resist chemical corrosion, also at elevated temperatures;
- to resist severe creep conditions in combination with oxidation and corrosion.

Consequently the rules for welding nickel and nickel alloys depend not only on the chemical composition but also on the required application.

5.6.2 Welding

To avoid hot cracking the area adjacent to the weld preparation shall be clean. S, Pb, Sb, Cd and Zn are detrimental impurities, which may be present in grease or paint. Acetone and equivalent solvents are used for cleaning, to avoid porosity. The oxide layer shall be removed by grinding to a bright metal surface appearance just prior to welding.

Figure 5.6.2 Weld preparation



Weld preparations should have a greater included angle than those used for carbon steel, to minimize the risk of lack of fusion defects due to the low fluidity of the weld metal.

For GMAW or GTAW only commercially pure argon or a mixture of argon and 5-10% hydrogen shall be used.

Care shall be taken to prevent oxidation of the filler wire tip during welding. Hence the wire tip shall remain in the protecting gas and be removed only after it is completely cooled down. If the wire tip is oxidized it shall be cut off. The welding consumables contain de-oxidizers such as Ti to prevent porosity in the weld metal.

The weld bead shall be ground smooth before the next weld bead is made, to minimize hot cracking especially at the stop/start positions.

5.6.3 Pure nickel

Two types of commercial pure nickel are available, one with a carbon content below 0.15% C and one with a carbon content below 0.02% C. Examples of trade names are nickel 200 and 201.

5.6.3.1 Welding nickel containing 0.15%-0.02% C maximum

The welding consumables shall have the same low carbon content and a low Ti content. For chlorine service at temperatures above 450 °C, weld metal containing Ti may be attacked. In this case a low-carbon type Ni wire without Ti shall be applied to prevent the selective attack. The porosity of the weld metal can be minimized by extreme cleaning of the weld area.

5.6.4 Ni-Fe-Cr

Examples of trade names are Incoloy 800 and 800H. The nickel content is about 32%.

5.6.4.1 Welding

In general these alloys are welded with consumables of the type 70% Ni-Cr-Fe, e.g. Inconel 182, Incoweld A. Ni-Fe-Cr alloys shall not be welded with Ni-Cu (Monel 190) or Cu-Ni (Monel 187) consumables, to avoid hot cracking.

Welding consumables with similar chemical composition to the base material are generally susceptible to hot cracking.

In pyrolysis furnaces, 70% Ni-Cr-Fe welds may be subject to catastrophic oxidation of carburized metal. The creep properties of this weld metal are also far inferior to those of the base material. For these conditions a 25Cr-35Ni-0.4C(+Nb) welding consumable should be used.

5.6.5 Ni-Fe-Cr-Mo

Example of a trade name is Incoloy 825. The nickel content is about 40%.

5.6.5.1 Welding

Two types of welding consumables are suitable, i.e. the 70% Ni-Cr-Fe-Mo and a matching type 40% Ni-Cr-Fe-Mo.

The matching type is more prone to hot cracking in the weld metal, especially at high heat inputs.

5.6.6 Ni-Cr-Fe and Ni-Cr-Fe-Mo alloys

Examples of trade names are Inconel 600 and 625. The nickel content is about 65%.

5.6.6.1 Welding

Welding consumables of matching chemical composition shall be used.

5.6.7 Ni-Cr-Mo alloys

Examples of trade names are Hastelloy C, C-276, C-4. The nickel content is about 55%.

5.6.7.1 Welding

The low-carbon grade, Hastelloy C-276, is not susceptible to weld decay in normal welding conditions. Prolonged exposure at elevated temperatures will cause carbide precipitation and loss of corrosion resistance.

The very low-carbon grade, Hastelloy C-4, is also not susceptible to weld decay. Exposure at elevated temperatures will hardly cause carbide precipitation and/or loss of ductility.

The Ni-Cr-Mo alloys shall be welded with consumables of matching chemical composition. Carbon and sulphur pick-up from the weld area shall be avoided by careful cleaning.

5.6.8 Ni-Mo alloys

Examples of trade names are Hastelloy B and B-2. The nickel content is about 65%.

5.6.8.1 Welding

This is a very low-carbon grade, not susceptible to weld decay but susceptible to embrittlement by the formation of intermetallic Ni-Mo compounds at prolonged exposure above 500 °C.

The alloy shall be welded with very low carbon consumables with matching composition. These can be provided by the plate manufacturer. Carbon and sulphur pick-up from the weld area shall be avoided by careful cleaning.

5.6.9 Ni-Cu

Examples of trade names are Monel 400 and Monel K500. The nickel content is about 65%.

5.6.9.1 Welding

The precipitation hardening alloy Monel K500 is not considered to be readily weldable. It is used for shafts and other parts. The normal Ni-Cu alloy is readily weldable; consumables with matching chemical composition shall be used, e.g. welding consumable Monel 190.

The PWHT temperature range of 550 to 600 °C shall be applied when PWHT is required (e.g. for corrosive conditions such as HF service).

5.7 ALUMINIUM AND ALUMINIUM ALLOYS

5.7.1 General

Aluminium and aluminium alloys can be divided into eight groups using the ASTM numbering system, which is based on the alloying elements.

Group	Major alloy elements	Weldability
1xxx	none	good
2xxx	Cu	bad
3xxx	Mn	good
4xxx	Si	good
5xxx	Mg	good
6xxx	Mg-Si	bad
7xxx	Zn	bad
8xxx	Sn	bad

Al and its alloys shall be ordered with a minimum elongation of 15%, to prevent deterioration of the parent metal properties by the welding heat.

5.7.2 Welding

Al and Al alloys are difficult to weld because of the aluminium oxide layer which, without the right precautions, will cause lack of fusion and porosity problems. Hot cracking may also result.

Only GMAW and GTAW processes are suitable for welding aluminium.

To obtain a good quality GTAW weld, an alternating current has to be applied to the arc in order to remove the oxide layer.

GMAW can be applied either with AC or DC, provided that with the latter the filler wire is positive, in order to remove the oxide layer.

Pure argon shall be used as shielding gas.

Pure argon as backing gas shall be applied for welding from one side only, to prevent excessive oxidation.

Where back-welding is feasible the root pass shall be ground away and rewelded.

5.7.2.1 Porosity

Porosity in aluminium welds is caused by:

- high solubility of hydrogen in the melting point region;
- presence of hydrogen in arc gases.

Joint design and welding position affect the degree of porosity, for example an overhead weld has a greater risk of gas entrapment. The adhering oxide layer contains a significant amount of hydrogen. It is therefore extremely important to break this layer open during welding .

5.7.2.2 Cracking

Aluminium alloys have a high thermal conductivity, thermal expansion and large melting temperature range and may be subject to solidification or liquation cracking (hot cracking). This cracking is mainly associated with alloying elements. Al-Si alloys with a silicon content below 0.7% are particularly susceptible to cracking.

5.7.2.3 Preheating

Preheating to 50 °C is required to remove any surface water, which would otherwise cause severe porosity.

5.7.2.4 Weld preparation

In general the same basic weld preparations for welding Al and its alloys are used as for steel, often with slightly greater included angles to allow good access and full fusion.

Because of the higher fluidity of Al and Al alloys in welding, weld pool support is of great importance, leading to more extensive application of temporary weld backing.

5.7.3 Aluminium (99.9%)

Pure aluminium is readily weldable provided the welding process characteristics are adhered to as described (5.6.2). However, a larger amount of porosity is likely than for Al alloys.

Welding consumables are micro-alloyed with Zr, Ti or B for grain refinement.

5.7.4 Aluminium-magnesium

Al-Mg alloys are readily weldable provided the electrical characteristics (5.6.2) are adhered to.

Welding consumables have a slightly higher magnesium content than the base material, to compensate for burn-off during welding, i.e. AlMg3 alloys are welded with AlMg5 consumables.

5.7.5 Aluminium-silicon

Aluminium-silicon alloys are mainly used for castings.

For welding, either AlSi5 or AlMg5 consumables are used. In the case of welding dissimilar alloys, e.g. AlSi and AlMg, AlMg5 consumables shall always be used since AlSi5 consumables will give a brittle layer of Mg_2Si.

5.8 COPPER AND COPPER ALLOYS

5.8.1 Welding

The main problem with welding is hot cracking. Therefore thorough cleaning and smooth weld appearance are very important. As copper and copper alloys easily oxidize, the time between weld preparation and welding shall be kept as short as possible. If joints are left for more than 12 hours an oxide layer is built up which will cause severe porosity problems during welding.

To remove the oxide layer careful grinding shall be carried out to a bright metal surface prior to welding. Cleaning with wire brushes will not remove the oxide layer; this can only be accomplished by grinding.

To minimize porosity in the weld metal the welding consumables shall contain de-oxidizers such as P, Zn.

The welding conditions differ when compared with low-carbon or low-alloy steels:

- tack welds have to be made at much smaller intervals;
- lack of side wall fusion may be a problem owing to the high heat conductivity;
- heat input per weld run should be minimized to avoid hot cracking.

5.8.2 Cu-Ni alloys

Cu-Ni alloys are normally welded either GMAW or GTAW with a 70Cu-30Ni consumable which contains de-oxidizers to avoid porosity.

The lower percentage Ni-containing consumables, e.g. 90/10 and 80/20, are more prone to hot cracking.

5.8.3 Cu-Al alloys

5.8.3.1 Welding

Cu-Al alloys shall be welded with matching consumables. The main problem with welding is the oxide layer which has to be broken.

GTAW with alternating current is normally used with a surface tension reducing flux, e.g. Cryolite. GMAW can also be used provided that direct current with straight polarity is used.

5.8.4 Cu-Zn alloys

With up to 3% zinc, no welding problems are encountered other than for normal copper.

5.8.5 Cu-Sn alloys

5.8.5.1 Welding

The alloys are susceptible to hot cracking and therefore thorough cleaning shall be applied.

High preheating temperatures (300 °C minimum) and slow cooling rates are required to avoid brittle intermetallic structures which are formed if cooling is too fast. Repair welding shall be avoided as much as possible.

5.9 TITANIUM, ZIRCONIUM AND TANTALUM

5.9.1 General

Ti, Zr and Ta have a high affinity for oxygen, nitrogen and hydrogen. Therefore, during welding care shall be taken to avoid embrittlement in the weld area from the absorption of oxygen, nitrogen and hydrogen from the atmosphere. Other impurities, like hydrocarbons (oil, grease), dirt and oxides in the weld area, will also cause weld embrittlement. Hence the weld area shall be cleaned carefully to a bright metal surface prior to welding.

During the welding operation the weld area shall be protected with pure inert gases like argon or helium. The required protection during welding can be provided in special welding chambers which are filled with a 99.996% pure inert gas (e.g. argon). This is often combined with GTAW in technically pure argon or helium gas.

For large sections special devices are constructed for GTAW to protect both the back and the front side of the weld area with trailing shields.

Welding of Ti, Zr and Ta requires highly skilled welders and shall be done only by specialized contractors. Welding shall be undertaken in segregated clean areas reserved for this specialist activity.

5.9.2 Weld preparation

Ti, Ta and Zr may be cut with oxygen. The final 5 mm shall be removed by grinding or machining. After plasma-arc cutting only 2 mm of the cut edges shall be removed by machining. For grinding, carborundum or corundum grinding wheels shall be used with an oil coolant. Dry grinding should be avoided, since small Ti, Ta or Zr particles could ignite and cause a fire.

Prior to welding, the weld preparation area shall be cleaned carefully to remove any impurities.

5.9.3 Welding

Ti, Ta and Zr shall be welded with matching consumables. During welding, the welding wires shall be kept carefully in the inert gas shielding atmosphere to prevent oxygen and nitrogen pick-up from the air. Ti, Ta and Zr are readily weldable materials provided that pick-up of impurities is avoided both from the atmosphere and from the weld preparation area. It is advisable to have a double inert gas stream during GTAW and GMAW.

Porosity in the weld metal is a common defect that is difficult to prevent completely.

Cracks in the welds are mainly caused by pick-up of iron-containing dust. Lack of fusion defects may occur.

The weld interpass temperature should be maintained below 100 °C.

5.9.4 Quality Control

A visual control shall be carried out immediately after the welding, prior to cleaning or rewelding. The oxygen content picked up can be visually checked by applying the following criteria:

a. Silver-grey: no oxygen pick-up;
b. Gold-yellow/light blue: slight oxygen pick-up but still acceptable;
c. Grey-blue/dark blue: unacceptable oxygen pick-up.

The colour shading indicates only whether oxygen absorption has taken place. Any presence of other impurities causing embrittlement can be determined only by bend tests and hardness tests. Therefore, bend tests shall be carried out on a regular basis during welding. In case of any bend failure all welds previously made shall be closely examined. It may be necessary to remove small samples of the weld in order to make Vickers hardness tests. In case of doubt the relevant welds shall be removed and rewelded.

The weld and HAZ shall be no more than 30 HV10 above the hardness of the parent metal.

Both bend tests and hardness tests on macro-sections shall be included in the weld procedure qualification.

5.10 CAST IRON

5.10.1 General

Welding of cast iron is only possible if special precautions and extreme care are taken.

The carbon content of cast iron is considerably higher than in normal steels.

When welded with steel consumables this causes unacceptably high hardnesses and brittle structures in the weld metal and HAZ, unless the cooling rate is very slow. In the case of high Ni consumables, high hardnesses will occur only in the HAZ.

If a casting has to be repaired a choice can be made from four alternatives:

- cold repair welding with high Ni (ENiFe-C1 or ENi-C1 types) consumables;
- hot repair welding with carbon steel consumables;
- braze welding (only for non-critical applications);
- mechanical devices, e.g. Metallock.

5.10.2 Cold repair welding with high Ni consumables

Cold repair welding with high Ni consumables is allowed only for castings in non-corrosive service.

A preheat and interpass temperature of 150-200 °C may be used to level off temperature gradient stresses. Heat input used shall be as low as possible. Shrinkage stresses shall be minimized by suitable selection of the welding sequence.

5.10.3 Hot repair welding with carbon steel consumables

Hot repair welding with carbon steel consumables should be applied for castings in corrosive service and when repairs over large areas are required.

Preheating shall be maintained during welding. Under no circumstances shall the temperature drop below 400 °C.

After welding, the temperature shall be maintained for 1 hour followed by slow cooling in an insulating firebrick or refractory blanket.

The cooling rate shall not exceed 50 °C per hour.

The high preheat temperatures followed by slow cooling will produce a weld metal with acceptable hardness values. For a corrosive service, a PWHT at 580-620 °C should be applied to further reduce the hardness level of the weld metal and HAZ.

For Ni-resist cast iron, a low-hydrogen consumable with a matching composition shall be used. Preheat temperatures of 450-600 °C shall be applied.

5.10.4 Braze welding

Braze welded repairs may be applied for non-critical applications.

If the melting point of the braze alloy is below 900 °C no hardening will occur in the HAZ. The hardness in the braze metal will not be too high.

The mechanical strength of the repair could be less than the strength of the parent casting.

Wetting of the braze joint may be a problem and may require special fluxes to remove oxides.

6. GUIDELINES FOR THE WELDING OF SPECIAL COMBINATIONS

6.1 STRIP LINING AND CLAD STEELS

6.1.1 Introduction

Clad steels are low-carbon or low-alloy steels inseparably covered with a relatively thin layer of a corrosion-resistant material, applied by rolling, explosion or overlay welding.

Reference is made to DEP 31.22.10.32-Gen. and DEP 31.22.20.31-Gen. for additional requirements applicable to welded pressure vessels constructed of integrally clad plate or with applied corrosion-resistant claddings.

Welding procedures shall be qualified using clad materials, not by qualifying the materials separately.

Examples of corrosion-resistant cladding materials are:

- martensitic or ferritic stainless steels (AISI 410/405);
- austenitic stainless steels (AISI 304/321/347/316);
- nickel or nickel alloys (Monel, Hastelloy, Inconel);
- copper or copper alloys (cupro-nickel, Al-bronze).

The weld metal joining the substrate shall have mechanical and physical properties as close as possible to (but no less than) those of the substrate. The weld metal joining the cladding layer shall have similar physical and chemical properties to those of the cladding. This requires special joint preparations and welding procedures. One of the following procedures should be followed:

- If welding is possible from the clad side:

  First, the base material is welded from one or both sides, depending on the thickness of this material. Then, the corrosion-resistant layer is welded from the clad side. (See section 6.1.2).

- If welding is only possible from the non-clad side:

  The required consumables shall be selected very carefully in order to produce an acceptable weld joint. (See section 6.1.3).

Another method for the application of a protective metal layer is strip lining. The corrosion-resistant lining is not fully bonded metallurgically to the base material. (See section 6.1.4).

6.1.2 Welding from two sides

6.1.2.1 General procedure

First the cladding material shall be removed next to the weld area to ensure that no contamination can occur from the cladding material into the weld of the base material. Clad removal shall be checked with a saturated copper sulphate solution. Cladding material inclusions in the weld of the base material may cause cracking owing to high hardness caused by martensite formation.

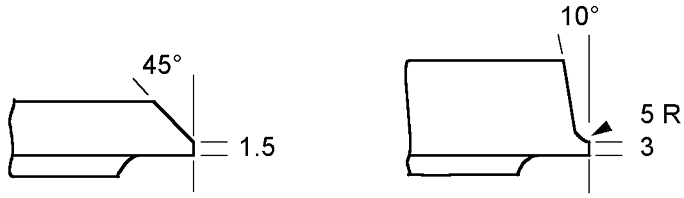
Next, the base material is welded from one or two sides as required for the thickness and material.

After completion of the base material weld the cladding layer is welded. For the first pass a buffer consumable shall be used. This buffer consumable shall have acceptable mechanical and chemical properties after dilution with the base material.

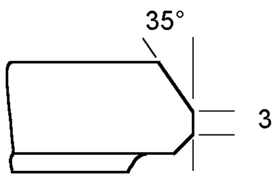
6.1.2.2 Weld preparation

The cladding material shall be removed from both sides of the weld preparation. The total amount removed depends on the welding process selected and the clad thickness but shall have a minimum width of 5 mm on each side of the weld preparation.

Figure 6.1.2 Typical edge preparations for welds in clad steels, welding from both sides



V-shaped joint Stripped-back joint U-shaped joint



X-shaped joint

Types of edge preparation used for butt welds in clad steels.

Dimensions are in mm.

The depth of the layer to be removed shall be the thickness of the cladding layer increased by (1 ± 0.5) mm.

The edges of the groove in the cladding shall be rounded off to prevent entrapment of slag.

The weld preparation for the base material shall be V, U or X-shaped in accordance with the standard for weld preparation for the type and thickness of this material. See Figure 6.1.2.

6.1.2.3 Welding procedure for the base materials

The base material shall be welded in accordance with the procedure for the base material involved.

6.1.2.4 Welding procedure for the cladding materials

Martensitic/ferritic or ferritic stainless steel cladding, e.g. AISI 410/405:

The procedure is to weld the first pass with a buffer electrode type AISI 309 and the subsequent passes also with an AISI 309 electrode. For special corrosion duties the second and subsequent weld passes are performed with matching weld metal. To reduce the hardening of the weld metal, a preheating at 150-200 °C should be applied.

Austenitic stainless steel cladding, e.g. AISI 304/304L/304H/321/321H/347/316/316L/317:

For stainless steel without Mo the first pass shall be welded with a buffer electrode of AISI 309 and for stainless steels containing Mo the electrode should be AISI 309Mo. The second and following passes shall be welded with a matching consumable, in accordance with (5.4). The weld area shall be cleaned thoroughly to minimize the risk of hot cracking. A ferrite content of 3-8% is acceptable for most applications.

Nickel or nickel-alloy cladding, e.g. pure nickel, Monel, Ni-Cr-Mo (e.g. Hastelloy B-2/C-4), Ni-Cr-Fe (e.g. Inconel 600/625):

The first weld layer shall be as shown below:

CLADDING MATERIAL	FIRST WELD LAYER
Pure nickel	Pure nickel
Monel	Monel
Ni-Cr-Mo	Incoweld A or Inconel 182
Ni-Cr-Fe	Incoweld A or Inconel 182

The second and subsequent layers shall be welded with matching electrodes to ensure that corrosion properties in the weld cap are equal to those of the cladding material. See (5.6).

To reduce the iron pick-up in the weld cap to an acceptable level, at least three passes shall be applied. The weld area shall be cleaned thoroughly to prevent hot cracking in the weld metal.

Copper and copper-alloy cladding:

The selected electrodes for the first layer of the weld in the cladding depend on the alloy. The welding of copper with matching electrodes may cause hot cracking in the weld metal owing to pick-up of iron or impurities. Copper penetration can cause liquation cracking in the weld metal. To avoid these problems for copper cladding materials, a buffer electrode is selected of Monel or Cu-8Al (e.g. Ampco 10 electrode). For Cu and Cu-Ni alloys a Monel buffer electrode is used, and for Al-bronze a Cu-8Al buffer electrode.

The second and following passes shall be welded with matching electrodes. However, claddings of 95 Cu-5 Ni, 90 Cu-10 Ni, 80 Cu-20 Ni and 70 Cu-30 Ni shall be welded with 70 Cu-30 Ni electrodes to prevent hot cracking in the weld metal.

6.1.3 Welding only from the non-clad side

6.1.3.1 General procedure

A special weld preparation is required to make a sound weld. Strict alignment is essential.

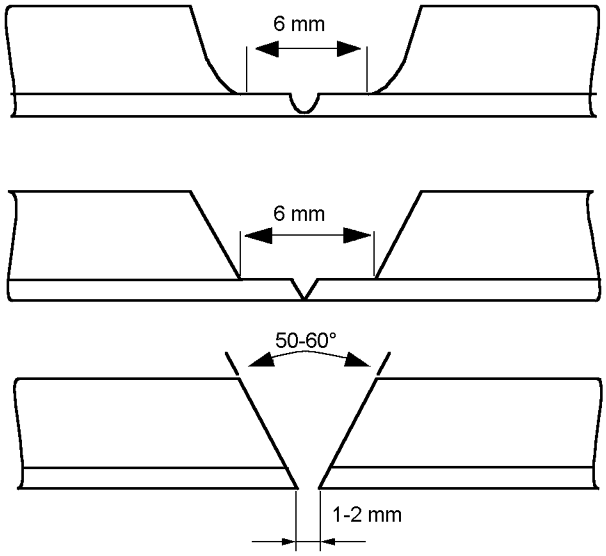
After welding the cladding material with matching electrodes, a buffer-type electrode shall be used to weld the base material. The selection of the buffer-type electrodes depends on the required properties of the weld metal and on the type of cladding.

So far the above procedure has been successful only for austenitic stainless steel claddings.

6.1.3.2 Weld preparations

Figure 6.1.3 shows weld preparations which are generally applied when clad steels are welded from the non-clad side only.

Figure 6.1.3 Weld preparations, welding only from clad side



6.1.3.3 Welding procedure for base material

Same as for (6.1.2.3).

NOTE: The procedures mentioned in (6.1.3.4) and (6.1.3.5) are not common engineering practices, they shall only be used as a last engineering option, and only with the approval of the Principal.

6.1.3.4 Welding with austenitic stainless steel electrodes (for services below 350 °C)

The root bead shall be made with matching electrodes in accordance with the rules for stainless steel welding.

For the second and subsequent passes, buffer electrodes of AISI 309Mo can be used. Inconel A should be used instead of AISI 309 electrodes if stress corrosion cracking may occur owing to chloride environment

For services above 350 °C these electrodes shall not be used due to the risk of cracking as a result of the difference in thermal expansion between the austenitic weld metal and the ferritic base material.

6.1.3.5 Welding with high-nickel electrodes

For the root bead, matching welding electrodes shall be used (4.5).

For the second and subsequent layers buffer electrodes of Incoweld A, Inconel 182 or Inconel 112/625 shall be used.

However, for hydrogen services at temperatures above 500 °C and/or for partial hydrogen pressures above 100 bar, high-nickel weld metal is prone to hydrogen embrittlement and shall not be used. The risk of hot cracking is larger for welds with high-nickel electrodes than for welds with austenitic stainless steel electrodes. The weld preparations shall therefore be cleaned thoroughly.

In process duties with sulphur corrosion above 350 °C, high nickel welds suffer from sulphidation and shall not be used.

6.1.4 Welding of austenitic stainless steel strip lining

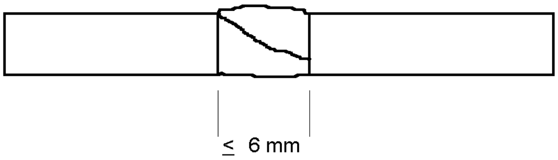
6.1.4.1 General

Two methods can be applied for the welding of strip lining. Depending on the gap width and the severity of the corrosive duty, either the two bead or the three bead method may be selected.

6.1.4.2 Two bead method

The two bead method, see Figure 6.1.3, shall be applied only for moderately corrosive service and if the gap width between the strips is no more than 6 mm.

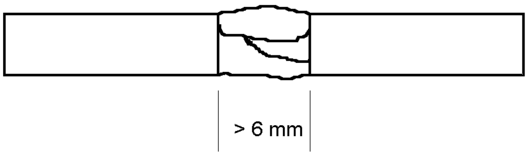
Figure 6.1.3 Two-bead method



6.1.4.3 Three bead method

For severe corrosive service, the gap shall be made greater than 6 mm, and the three bead method (Figure 6.1.4) shall be used.

Figure 6.1.4 Three-bead method



6.1.4.4 Welding consumables

For both methods AISI 309Mo buffer electrodes shall be used.

6.2 DISSIMILAR METALS

Dissimilar welds are not recommended engineering practice, and shall only be used as a last engineering option.

For hydrogen service, welds shall not be made between ferritic and austenitic steels unless approved by the Principal.

6.2.1 Introduction

Two main groups of dissimilar weld joints can be identified:

1. Equal physical properties

   Joints between ferritic materials (carbon, Mo and Cr-Mo steels).
   Joints between austenitic materials (AISI 304, 321, 317, 347).
   Joints between high-nickel alloys (Monel, Inconel 700, Hastelloys B and C).

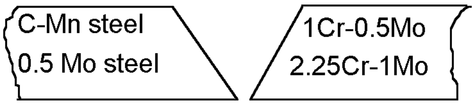
2. Different physical properties
   Joints between ferritic and austenitic materials.
   In this case the selection of weld metal largely depends on the service conditions, such as temperature, thermal cycling, possible galvanic corrosion, etc.

The following two rules shall apply for dissimilar weld joints:

Rule 1:
Dissimilar joints between ferritic low-alloy and carbon steel are made by using filler material with a chemical composition matching the lower-grade material.

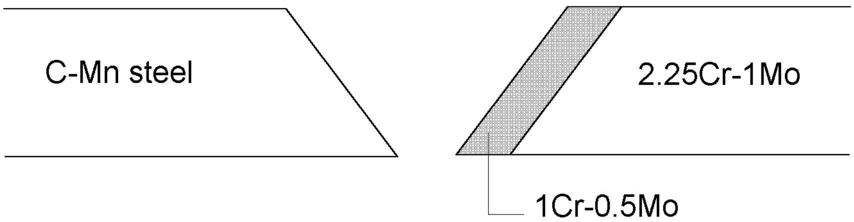
Rule 2:
Dissimilar joints between austenitic and ferritic steels are made by using a buffer filler material.

6.2.2 Welding carbon manganese or 0.5 Mo steels to Cr-Mo steels



For post-weld heat treatment of the specified materials the following guidelines should be followed:

- An intermediate temperature shall be chosen between the PWHT temperature ranges of the two materials, but lower than the tempering temperature of the lowest grade. The holding time specified for the higher grade shall be increased by 1.5 times.
- However, if the PWHT temperature so selected will not result in the individual base materials and weld metal achieving the specified mechanical properties, then a buffering technique shall be applied on the higher grade side as shown in the example below:



After buffering, PWHT shall be applied at the temperature suitable for the buffered base material (2.25Cr-1Mo in the above example). After this PWHT, the joint shall be completed and PWHT shall then be carried out at the temperature suitable for the lower grade base material (C-Mn steel in the above example).

CAUTION: For dissimilar welds in steel operating in the creep range (e.g. 9Cr-1Mo or 9Cr-1Mo modified to 2.25Cr-1Mo steels) carbon depletion in the low Cr base material or weld can occur (carbon diffusion out of low chromium material into the neighbouring high chromium steel) and will adversely effect the creep life.

6.2.3 Welding of C steel to Ni or Cu alloys

C-Mn steel shall be welded to Ni alloys with Incoweld A, Inconel 182 or Inconel 82 consumables.
C steels shall be welded to Ni or Cu alloys with Monel 187/190 (ENiCu7).
C steels shall be welded to Ni-Cr-Fe alloys with Incoweld A.
C steel shall be welded to aluminium bronze with special buffer-type electrodes of Cu-8Al or Cu-10Al-1Fe.

6.2.4 Welding of ferritic to austenitic steel

Welds between the austenitic steel and the ferritic steel are potentially sensitive to cracking. The sensitive area is the local hard zone in the immediate vicinity of the fusion line in the weld metal. The risk of cracking increases with temperature for reasons of thermal fatigue (start-up/shut-down) particularly in the case of AISI 309 type of welds, and its application is therefore restricted to a maximum operating temperature of 350 °C.

NOTE: This restriction does not apply for short-term temperature excursions above 350 °C (e.g. hot hydrogen stripping) because there is an incubation period necessary before hot hydrogen attack occurs.

Care should be taken to avoid hot cracking in the weld metal. The weld preparation shall be cleaned carefully and every weld bead deposited shall be ground smooth prior to the next weld bead.

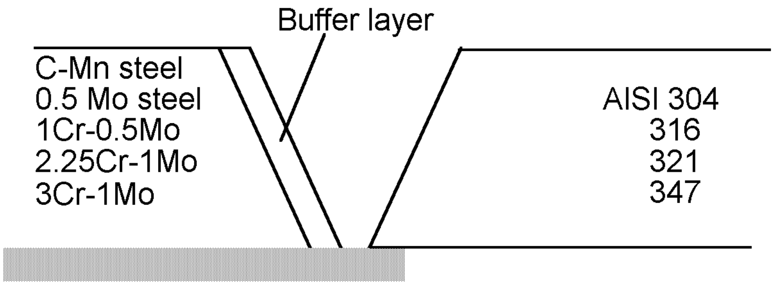
Chemical cleaning or pickling shall not be applied.

In process duties with sulphur corrosion above 350 °C, flanged connections are required due to possible sulphidation of high-nickel welds.

During weld procedure qualification, a micro-hardness survey on an etched sample shall be done on the fusion line between the buffer layer and base material. The hard zone on the interface may contain individual hard spots provided there is not a continuous network (sequence) of hard spots.

Where post weld heat treatment is required for the ferritic material the following welding sequence can be applied.

1. Buttering the ferritic weld bevel with a buffer type consumable followed by PWHT. After PWHT the buffer layer is then welded matching to the austenitic material.

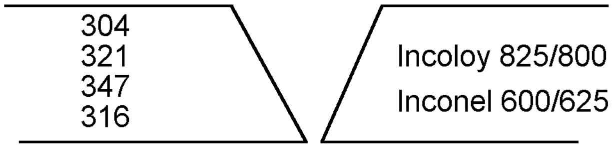


   This technique is particularly suitable for wall thickness above 25 mm.

2. For wall thicknesses below 25 mm a stainless steel safe end welded to the ferritic material with a buffer consumable followed by PWHT is recommended, as buttering buffer layer onto "thin" materials is cumbersome. After PWHT the stainless steel safe end is welded matching to the austenitic material.

NOTE: Safe ends may also be applied above wall thicknesses of 25 mm.

6.2.5 Welding of austenitic stainless steel to Ni-Cr-Fe alloys



For high-temperature applications, Incoweld A or Inconel 82 shall be used.

For low-temperature applications, Inconel 112/625 or Incoweld A shall be used.

6.3 WELDING OF TUBES TO TUBE SHEETS

6.3.1 Introduction

The integrity of a heat exchanger greatly depends on the tube to tube sheet joint. Tube to tube sheet joints shall also comply with DEP 31.21.01.30-Gen.

The choice of connection shall be made by process, design and materials/corrosion engineering. If a welded tube end connection is selected, Appendix 1 gives different joint options and Appendix 2 summarises the welding procedure test specimen requirements.

6.3.2 Welding procedure qualification

6.3.2.1 General

No production welding shall be carried out until the proposed welding procedures have been qualified.

6.3.2.2 Procedure test piece

The procedure test piece shall be welded in the same position as the production welding to be done. The welding sequence/configuration shall also be part of the procedure qualification.

All tubes and plate material used for procedure testing shall be of the same material specification and dimensions as those proposed for production. In the case of duplex stainless steels the tube sheet heat sink shall be simulated and the ferrite content of base and weld materials shall be determined; for acceptance criteria, see (5.5.4).

6.3.2.3 Examination of test pieces

The completed test pieces shall be examined as follows:

a) Visual examination;
b) Radiographic examination;
c) Macroscopic examination after sectioning as shown in Appendix 2, with hardness measurements where appropriate;
d) The weld shall meet the requirements of 6.3.2.6;
e) Weld strength test as shown in Appendix 3.

6.3.2.4 Welder qualification

Every welder employed on tube end welding shall demonstrate his competence by making a test piece in accordance with approved welding procedure qualification record.

If a welder has successfully passed the appropriate qualification tests within the last 6 months and has been regularly employed in this type and size of weld since passing his test, and there is evidence that the welder has continued to make satisfactory welds, he may be accepted without further qualification at the discretion of the Principal.

6.3.2.5 Weld qualification requirements

For a summary of tests required, see table below.

Type of Test Required	Procedure qualification	Welder qualification
Visual examination	Yes	Yes
Macro-examination	Yes	Yes

6.3.2.6 Weld quality

The specified tests shall be carried out to the satisfaction of the Principal and the following requirements apply:

	Standard	Special
cracks	none permitted	none permitted
slag/porosity	maximum 0.25 x t	none permitted
lack of fusion	none permitted	none permitted
burn-through of pipe bore	none permitted	none permitted
excessive weld spatter/overhang	none permitted	none permitted
effective weld thickness	0.7x t	t

where t = nominal tube thickness

6.3.3 Examination of production welds

After each weld run, the weld and internal tube surface for at least 3 mm beyond the fusion zone shall be thoroughly cleaned, wire brushed, and examined. All defects not permitted shall be repaired.

If specified by the Principal, each weld run shall be examined by PT (for fully austenitic materials) or examined by MT (for ferrous materials).

6.3.4 Low pressure pneumatic test

After welding and before hydrostatic testing, the assembly shall be tested for leaks by applying air pressure of 0.5 bar gauge.

While the shell is under pressure a simple soap or detergent test shall be used to indicate escapes of air from leaks.

When specified by the Principal, a tracer such as halogen gas or helium shall be added to the pressurizing air, and a suitable detector used to locate leakages.

Other methods, e.g. the leak detection method described in BS 3636, may be employed if approved by the Principal.

If specified by the Principal, leak testing shall be carried out after the completion of each run in multi-run welds.

All suspect weld locations shall be marked for repair.

6.3.5 Repairs

On completion of the pneumatic test (6.3.4), any leaks disclosed shall be repaired and retested until all faults are remedied.

Rather than making local repairs, faulty welds shall be completely removed to sound metal and rewelded using the qualified procedure.

Minor faults associated with fully automatic TIG welding incorrect settings or tracking, may be rectified by rewelding at corrected settings. If the welds still remain defective, they shall be removed and repaired manually by the TIG process using appropriate filler metal addition.

6.3.6 Expansion after welding

If expansion is to be performed after welding, the sequence shall be as follows:

Weld,
pneumatic test (6.3.4),
PWHT (if applicable),
expand.

If expansion is to be performed after welding, for services where stress corrosion cracking may occur, the sequence shall be as follows:

Weld,
pneumatic test (6.3.4),
expand,
PWHT.

The expansion shall be lightly done, with the object of sealing the back face crevice in the tube hole.

The expanding equipment shall have limiting controls which will ensure that tube wall thinning is between 3% and 5% of the original wall thickness. The Manufacturer shall demonstrate by procedure tests that the equipment settings to be used will achieve the required thinning.

6.3.7 Hydrostatic testing

The hydrostatic test shall be carried out after all welding, pneumatic tests, tube expansion, PWHT and NDE has been completed and accepted.

The tube plate face, the welds and the internal surfaces of the tubes to a length of approximately 15 mm shall be thoroughly cleaned by a suitable method. Any grease present shall be removed either by the use of a solvent or by steam jets. A coating of white-wash may then be applied to assist in detecting leaks.

Where water is employed for pressure testing, 2% volume of wetting agent shall be added to the water and, for carbon steel assemblies, 0.2% sodium nitrite shall be added as a corrosion inhibitor.

The test water quality shall satisfy the requirements of DEP 61.10.08.11-Gen.

7. REFERENCES

In this DEP reference is made to the following publications:

NOTE: Unless specifically designated by date, the latest edition of each publication shall be used, together with any amendments/supplements/revisions thereto.

SHELL STANDARDS

Index to DEP publications and standard specifications	DEP 00.00.05.05-Gen.
Metallic materials Requirements for prevention of brittle fracture of equipment in low-temperature service (45 °C or below) and equipment containing liquefied gas or lethal substances	DEP 30.10.02.31-Gen.
Shell-and-tube heat exchangers (Amendments/Supplements to TEMA standards)	DEP 31.21.01.30-Gen.
Pressure vessels (Amendments/Supplements to BS 5500)	DEP 31.22.10.32-Gen.
Pressure vessels (Amendments/Supplements to ASME Section VIII, Division 1 and Division 2)	DEP 31.22.20.31-Gen.
Linepipe for use in oil and gas operations under sour conditions (Amendments/Supplements to API Spec 5L)	DEP 31.40.20.31-Gen.
Field inspection prior to commissioning of mechanical equipment	DEP 61.10.08.11-Gen.
Equipment made of 2.25 Cr-1 Mo steel in quenched and tempered condition	W-6-1/2/3

AMERICAN STANDARDS

Chemical Plant and Petroleum Refinery Piping	ANSI/ASME B31.3
ASME Boiler and Pressure Vessel Code Section VIII - Rules for Construction of Pressure Vessels	ASME VIII

Issued by:
American Society of Mechanical Engineers
345 East 47th Street
New York, NY 10017
USA.

Material requirements sulfide stress cracking resistant metallic materials for oil field equipment	NACE MR0175

Issued by:
National Association of Corrosion Engineers
P.O. Box 218340
Houston, Texas 77218
USA.

BRITISH STANDARDS

Methods for proving the gas tightness of vacuum or pressurised plant	BS 3636
Metal-arc welding of carbon and carbon manganese steels	BS 5135

Issued by:
British Standards Institution
389 Chiswick High Road
London W4 4AL, England
United Kingdom.

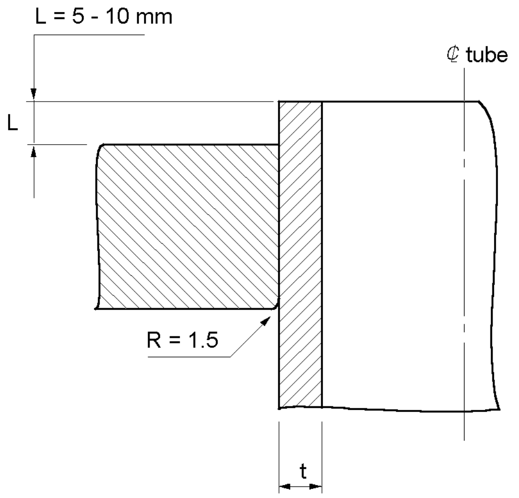
DUTCH STANDARDS

WPSelect, Collection of Standard Welding Procedures WPSelect

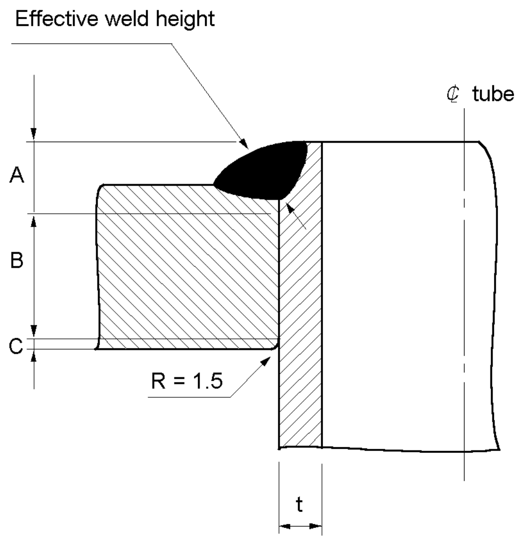
Issued by:
The Netherlands Welding Institute (NIL)
Krimkade 20
2251 KA Voorschoten
The Netherlands.
Tel: +31-71-5611211
Fax: +31-71-5611426

APPENDIX 1 STANDARD AND SPECIAL QUALITY TUBE TO TUBE SHEET JOINTS

SMAW



- Materials: C/Mn steel, stainless steels
- Minimum distance between tubes: 2.5 x t or 8 mm
- Not suitable for stoving lacquer
- Tubes can be fixed either by slight rolling or 3 points expander

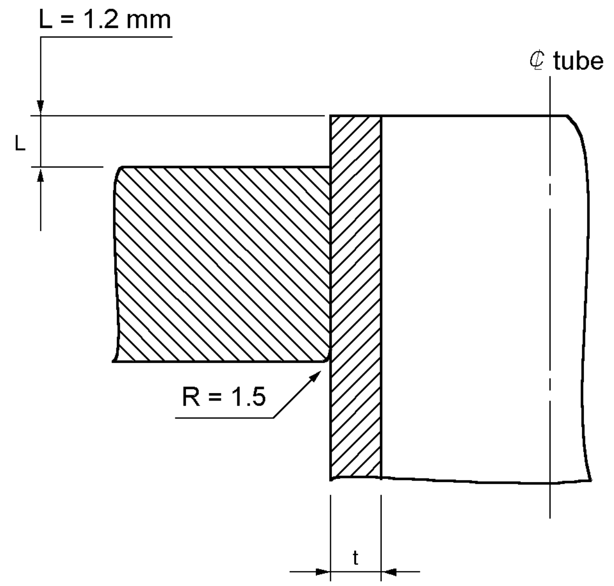


A = minimum 5t
B = effective rolling length
C = minimum 2t

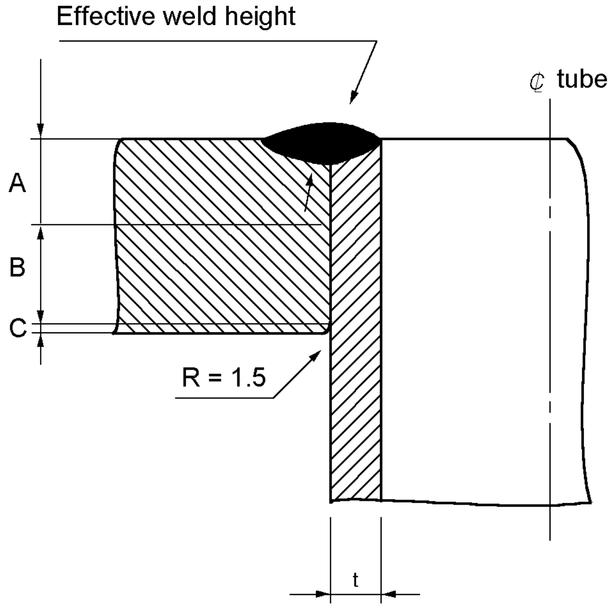
- Tube expansion after welding and only when specified
- Rolling direction from weld into tube sheet

APPENDIX 1 STANDARD AND SPECIAL QUALITY TUBE TO TUBE SHEET JOINTS (cont'd)

GTAW



- Materials: C/Mn steel, stainless steel
- Automatic GTAW welding can be used
- For tube fixation a 3-points expander may be used

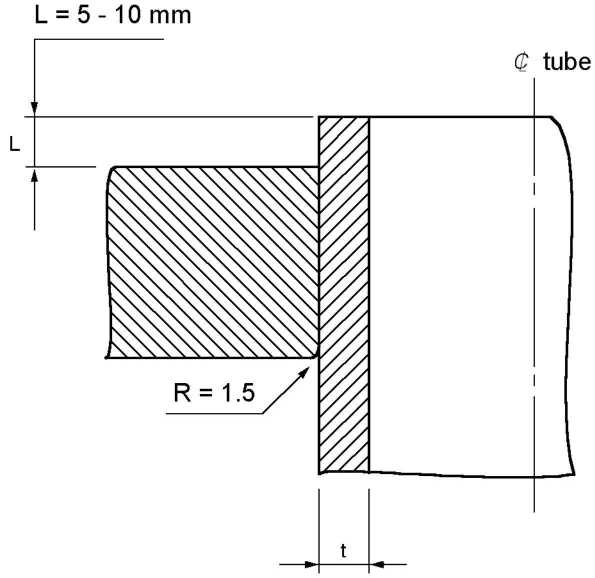


A = minimum 5t
B = effective rolling length
C = minimum 2t

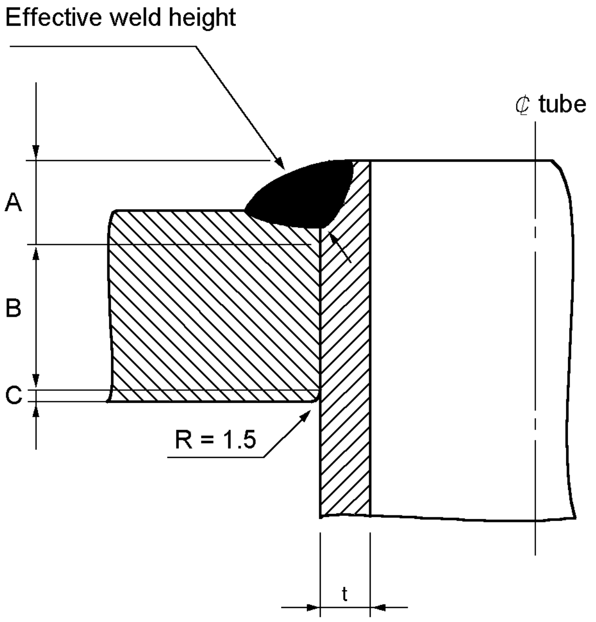
- Tube expansion after welding and only when specified

APPENDIX 1 STANDARD AND SPECIAL QUALITY TUBE TO TUBE SHEET JOINTS (cont'd)

GTAW/SMAW



- Materials: C/Mn steel, stainless steels
- Minimum distance between tubes: 2.5 x t or 8 mm
- Combination 1st layer GTAW - 2nd layer SMAW allowable
- Tubes may not be fixed by either rolling or tack welding when GTAW is applied
- Not suitable for application of stoving lacquer

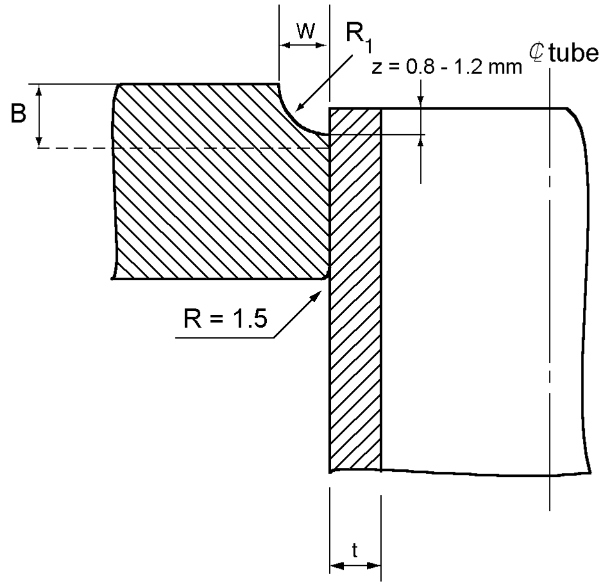


A = minimum 5t
B = effective rolling length
C = minimum 2t

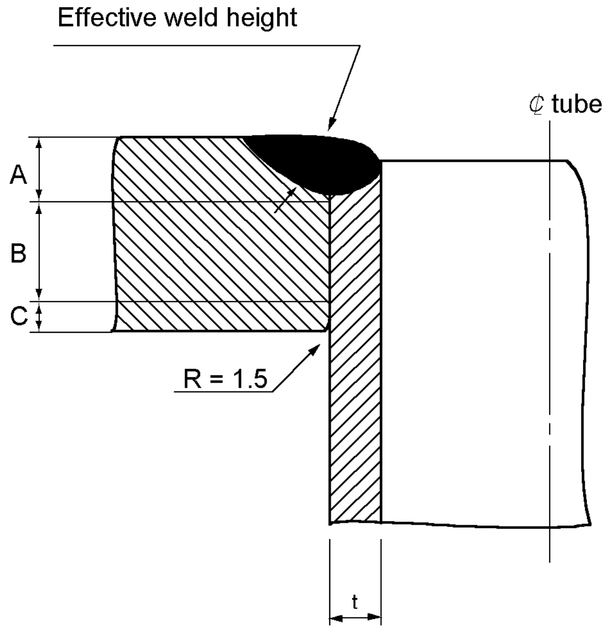
- Tube expansion after welding after first layer only when specified

APPENDIX 1 STANDARD AND SPECIAL QUALITY TUBE TO TUBE SHEET JOINTS (cont'd)

GTAW



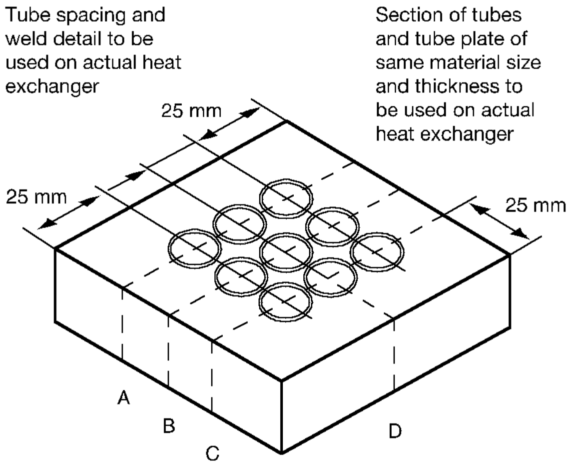
- Materials: stainless steels and high alloys (cu, Ni etc.)
- Cladding tube plates: clad thickness B such that no fusion will occur with the base material
- $W=t$, $R_1=t$, $B>t$
- Tubes may only be fixed with 3 points expander



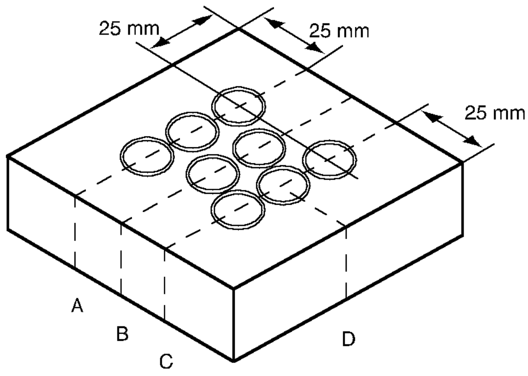
A = minimum 5t
B = effective rolling length
C = minimum 2t

- Tube expansion after welding and only when specified

APPENDIX 2 EXAMINATION OF WELDING QUALIFICATION TEST PIECES FOR TUBE TO TUBE SHEET JOINTS



Test specimen for square pitch



Test specimen triangular pitch

Macroscopic Examination

Each weld region on one surface of each of the saw cuts A, B and C shall be carefully prepared by emerying to a minimum 180's grit emery finish, and then etched in a suitable reagent to reveal the weld structure.

Saw cut D shall be made at a stop/start position.

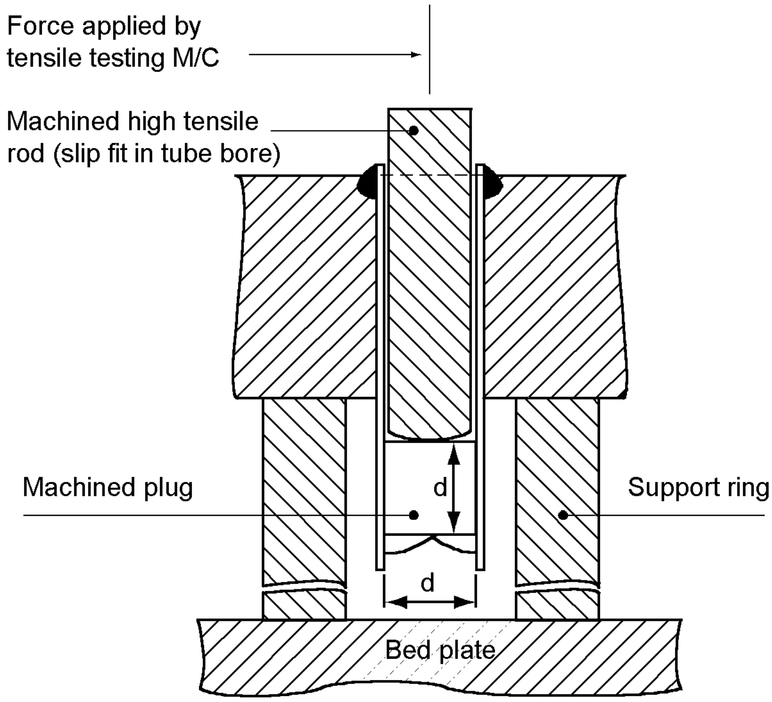
The effective weld height shall be measured on all sections. Using an electronic calculator or by plotting the values on probability paper, the average effective weld height and the 1% minimum weld height can be determined.

A welding procedure can be considered satisfactory when average and minimum weld height values are not much different. In this respect automatic GTAW welding and GTAW welding has a better quality than SMAW, although the average weld height may be less.

Weld strength test rigs

See Appendix 3.

APPENDIX 3 ALTERNATIVE WELD STRENGTH TEST RIGS



Load is applied slowly, to ensure no shock loading is applied and test continued until failure of tube or weld results.