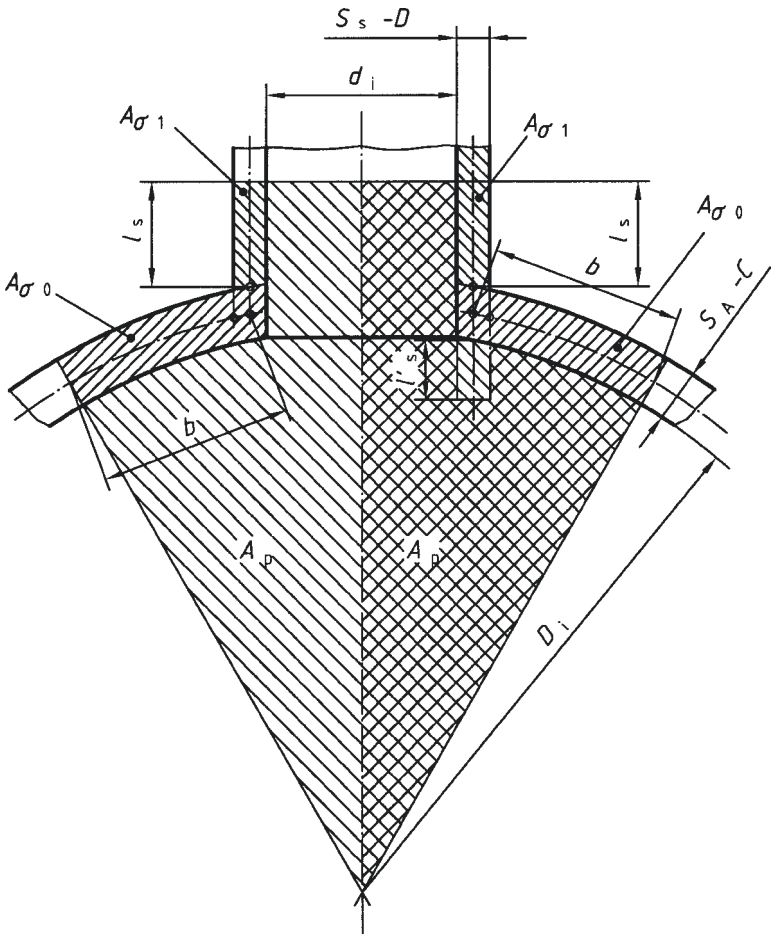


Figure 23 — Calculation scheme for spherical shells

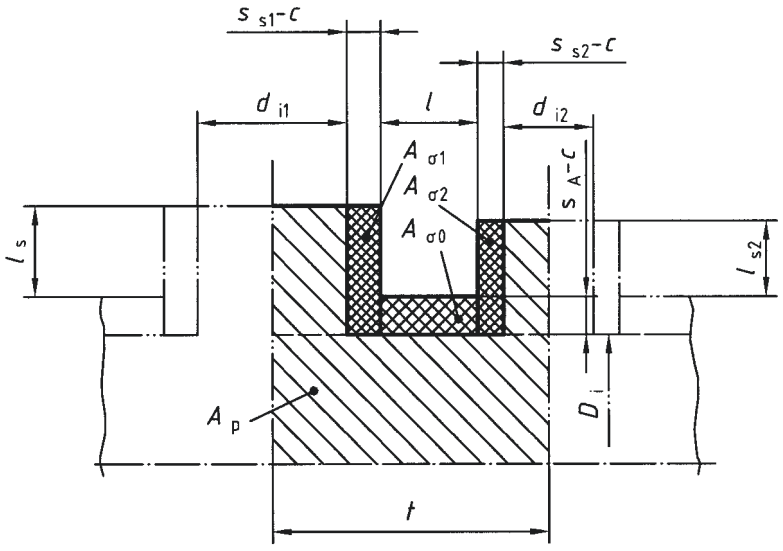
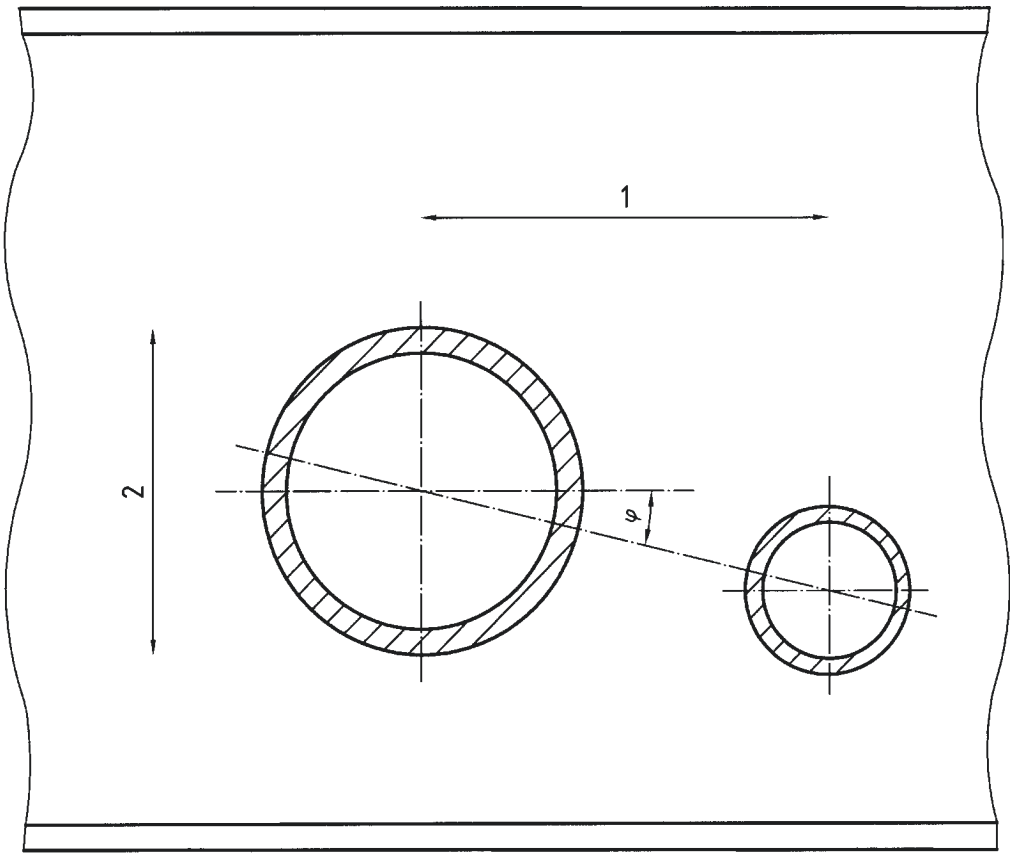


Figure 24 — Calculation scheme for adjacent nozzles in a sphere or in a longitudinal direction of a cylinder



Key

1 Longitudinal direction
2 Circumferential direction

Figure 25 — Openings between longitudinal and circumferential direction

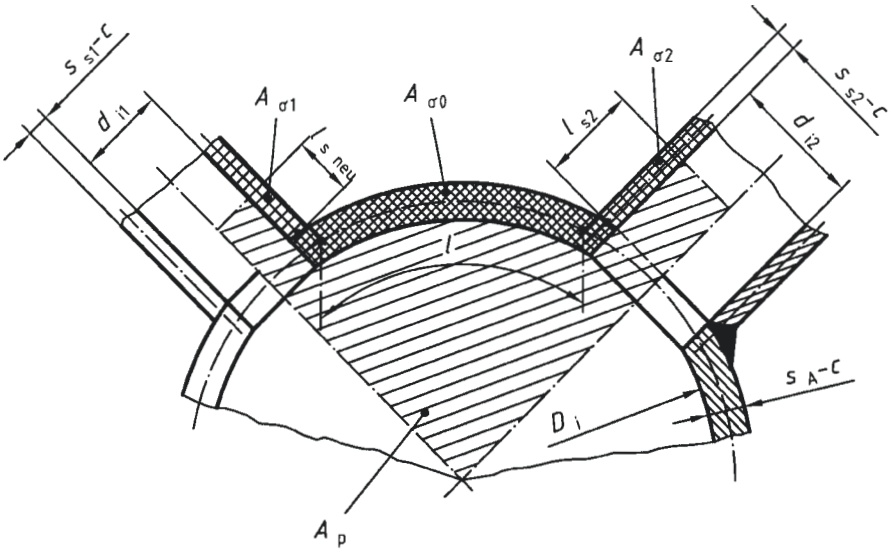


Figure 26 — Calculation scheme for adjacent nozzles in a sphere or in a circumferential direction of a cylinder

5 Fabrication

5.1 General

5.1.1 The manufacturer, or his or her sub-contractor, shall have equipment available to ensure manufacture and testing in accordance with the design.

5.1.2 The manufacturer shall maintain:

— a system of material traceability for pressure bearing parts used in the construction of the inner vessel;

— design dimensions within specified tolerances;

— necessary cleanliness of the inner vessel, associated piping and other equipment which could come in contact with the cryogenic fluid.

5.1.3 The base materials, listed in annex K, additionally specified with the extra requirements given in the main body of this European Standard, are suitable for and may be employed in the manufacture of the cryogenic vessels conforming to EN 13458.

NOTE Materials listed in annex L cannot be used without European approval of pressure equipment materials (EAMs) or Particular material appraisal (PMA).

5.2 Cutting

Material may be cut to size and shape by thermal cutting, machining, cold shearing or other appropriate method. Thermally cut material shall be dressed back by machining or grinding.

5.3 Cold forming

5.3.1 Austenitic stainless steel

Heat treatment after cold forming is not required in any of the following cases:

1) for operating temperatures down to – 196 °C

   a) the test certificate for the base material shows an elongation at fracture A_5 of more than 30 % and the cold forming deformation is not more than 15 % or it is demonstrable that the residual elongation is not less than 15 %;

   b) the cold forming deformation is greater than or equal to 15 % and it is demonstrated that the residual elongation is not less than 15 %;

2) for operating temperatures below – 196 °C, the test certificate for the base material shows an elongation at fracture A_5 of more than 30 % and the cold forming deformation is not more than 10 %;

3) for formed heads, the test certificate for the base material shows an elongation at fracture A_5:

   — not less than 40 % in the case of wall thicknesses not more than 15 mm at design temperatures down to - 196 °C;

   — not less than 45 % in the case of wall thicknesses more than 15 mm at design temperatures down to - 196 °C;

   — not less than 50 % at design temperatures below - 196 °C.

Where heat treatment is required this shall be carried out in accordance with the material standard.

Cold forming deformation can be calculated according to EN 13445-4.

5.3.2 Ferritic steel

Requirements for post forming heat treatment are:

a) material for the outer jacket, including cold formed ends with or without joggled joints, does not require post forming heat treatment;

b) 9 % Ni steel requires post forming heat treatment where cold forming deformation exceeds 5 %. Fully certified quenched and tempered or double normalised and tempered 9 % Ni steel shall be stress relieved at 560 °C to 580 °C. Forming and stress relieving may be performed in several stages. A test piece taken from the parent material that accompanies the formed part through all stages of heat treatment shall be tested after all heat treatment is complete to demonstrate that the material mechanical properties conform to the requirements of the material standard;

c) for the following ferritic steels used for the inner vessel, post forming heat treatment is not required where the forming deformation is not more than 5 %:

   1) nickel alloyed steels suitable for low temperature use;

   2) carbon and carbon-manganese steels:

      — where $R_m \leq 530$ N/mm^2;

      — or where $530 < R_m \leq 650$ N/mm^2 and $R_{0,002} \leq 360$ N/mm^2.

When heat treatment is required, suitable heat treatments after cold forming are normalising, normalising (double) plus tempering, quenching plus tempering or solution annealing.

Parameters given by the base material manufacturer in the test certificate shall be taken as an indication or recommendation for heat treatments except that other heat treatments may be applied if the procedure is qualified and the product or a test piece representing the product is tested after forming and heat treatment.

5.3.3 Aluminium or aluminium alloy

Cold formed ends made from aluminium or aluminium alloy do not normally require post forming heat treatment, unless there is a risk of stress corrosion in service. Treatment shall be carried out in accordance with the material standard.

5.4 Hot forming

5.4.1 General

Forming shall be carried out in accordance with a written qualified procedure. The forming procedure shall specify the heating rate, the holding temperature, the temperature range and time for which the forming takes place and shall give details of any heat treatment to be given to the formed part.

5.4.2 Austenitic stainless steel

Material shall be heated uniformly in an appropriate atmosphere without flame impingement, to a temperature not exceeding the recommended hot forming temperature of the material. When forming is carried out after the temperature of the material has fallen below 900 °C the requirements of 5.3.1 shall be complied with.

5.4.3 Ferritic steel

Requirements for post forming heat treatment are:

a) 9 % Ni steel that is hot formed shall be double normalised and tempered or quenched and tempered in accordance with the material standard to establish the material properties specified therein. Test piece(s) shall be provided and tested in accordance with the material standard;

b) ferritic steel that is hot formed shall be heat treated in accordance with the material standard to establish the material properties specified therein:

   — air quenched steels shall be tempered subsequently;

   — test pieces shall be provided and tested in accordance with the material standard;

   — for normalised steels a post forming heat treatment is not necessary if the hot forming is done within the temperature range specified in the material standard ; further test pieces are not required.

5.4.4 Aluminium or aluminium alloy

Post forming heat treatment may be omitted if evidence in the form of a procedure qualification can be provided showing that the elongation at fracture A_5 of the formed material is not less than 10 %.

5.5 Manufacturing tolerances

5.5.1 Plate alignment

Except where a tapered transition is provided, misalignment of the surfaces of adjacent plates at welded seams shall be:

— for longitudinal seams, not more than 15 % of the thickness of the thinner plate up to a maximum of 3 mm;

— for circumferential seams, not more than 25 % of the thickness of the thinner plate up to a maximum of 5 mm.

Where a taper is provided between the surfaces, this shall have a slope of not more than 30°. The taper may include the width of the weld, the lower surface being built up with added weld metal if necessary. Where material is removed from a plate to provide a taper, the thickness of either plate shall not be reduced below that required for the design.

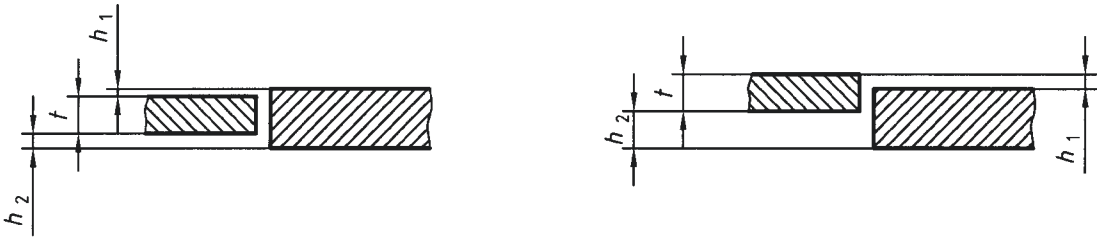
The distance between either surface of the thicker plate and the centre line of the thinner plate of tapered seams shall be:

— for longitudinal seams, not less than 35 % of the thickness of the thinner plate;

— for circumferential seams, not less than 25 % of the thickness of the thinner plate.

In no case shall the surface of any plate lie between the centre lines of the two plates.

These requirements are illustrated in Figure 27.



Key

h, h_1, h_2 is the surface misalignments

t is the thickness of the thinner plate

e is the distance from the surface of the thicker plate to the centreline of the thinner plate

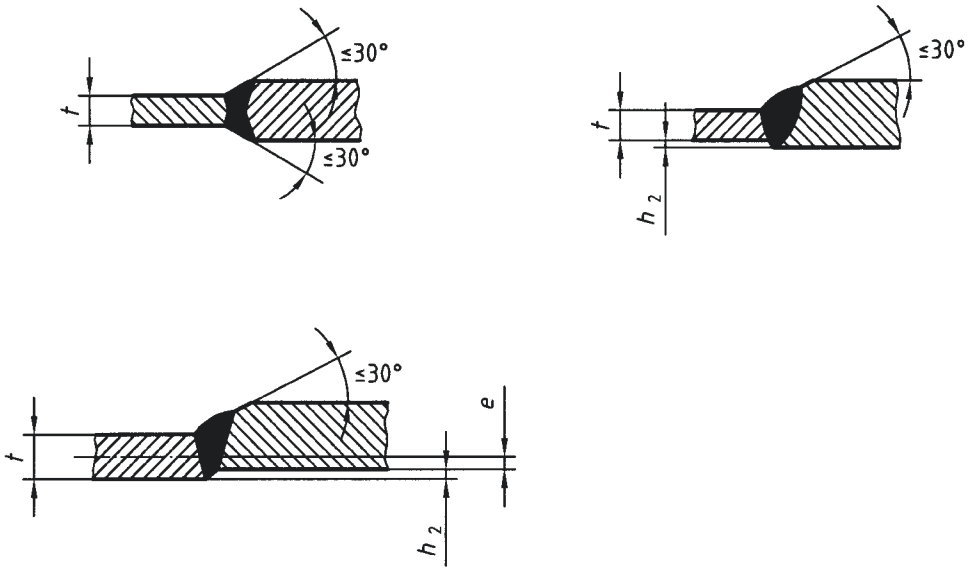
For longitudinal seams:

$h_1 \leq 0{,}15\ t$ and $h_2 \leq 0{,}15\ t$

For circumferential seams:

$h_1 \leq 0{,}25\ t$ and $h_2 \leq 0{,}25\ t$

a) — Seam which do not require a taper



For longitudinal seams:

$h \leq 0{,}15\ t$ and

$$e = \frac{t}{2} - h \geq 0{,}35\ t$$

For circumferential seams:

$h_2 \leq 0{,}25\ t$ and

$$e = \frac{t}{2} - h \geq 0{,}25\ t$$

b) — Seams which do require a taper

Figure 27 — Plate alignment

5.5.2 Thickness

The thickness of the vessel shall not be less than the design thickness. This shall be taken as the thickness of the vessel after manufacture and any variations in thickness shall be gradual.

5.5.3 Dished ends

The depth of the dishing, excluding the straight flange, shall not be less than the theoretical depth. The knuckle radius shall not be less than specified and the crown radius shall not be greater than specified. Any variation of the profile shall not be abrupt but shall merge gradually into the specified shape

5.5.4 Cylinders

5.5.4.1 The actual circumference shall not deviate from the circumference calculated from the specified diameter by more than ± 1,5 %.

5.5.4.2 The out of roundness u calculated from the expression:

$$\text{out of roundness } u = \frac{200(D_{max} - D_{min})}{D_{max} + D_{min}} \quad \text{in \%} \tag{35}$$

shall be not more than the values shown in Table 1.

Table 1 — Permitted out of roundness

Wall thickness to diameter ratio	Permitted out of roundness for	
	internal pressure	external pressure
$s/D \leq 0{,}01$	2,0 %	1,5 %
$s/D > 0{,}01$	1,5 %	1,5 %

The determination of the out-of-roundness need not consider the elastic deformation due to the dead-weight of the pressure vessel. At nozzle positions, a greater out-of-roundness may be permitted if it can be justified by calculation or strain gauge measurement. Single dents or knuckles shall be within the tolerances. Dents shall be smooth and their depth which is the deviation from the generatrix of the shell shall not exceed 1 % of their length or 2 % of their width respectively. Greater dents and knuckles are permissible provided they have been proven admissible by calculation or by strain measurements.

Irregularities in profile (checked by a 20° gauge) shall not exceed 2 % of the gauge length. This maximum value may be increased by 25 % if the length of the irregularities does not exceed one quarter of the length of the shell part between two circumferential seams with a maximum of 1 m. Greater irregularities require proof by calculation or strain gauge measurement that the stresses are permissible.

Furthermore, where irregularity in the profile occurs at the welded seam and is associated with "flats" adjacent to the weld the irregularity in profile or "peaking" shall not exceed the values given in Table 2.

A conservative method of measurement (covering peaking and ovality) shall be by means of a 20° profile gauge (or template).

The use of such a profile gauge is illustrated in Figure 28. Two readings shall be taken, P_1 and P_2 on each side of the seam, at any particular location, the maximum peaking is taken as being equivalent to 0,25 (P_1 + P_2).

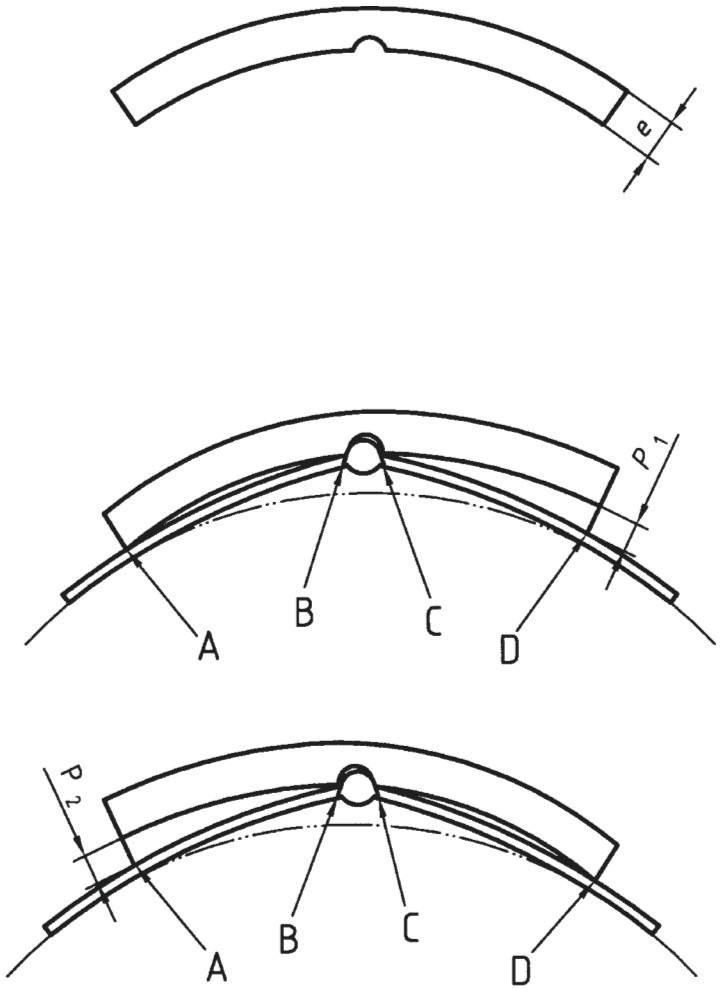


Figure 28 — Gauge details

Measurements should be taken at approximately 250 mm intervals on longitudinal seams to determine the location with the maximum peaking value. Use of other types of gauges such as bridge gauges or needle gauges are not prohibited. The maximum peaking value permitted is given in Table 2.

Table 2 — Maximum permitted peaking

Dimensions in millimetres

Vessel ratio wall thickness *s* to diameter *D*	Maximum permitted peaking
$s/D \leq 0{,}025$	5
$s/D > 0{,}025$	10

For all ratios a maximum permitted peaking is e.

For cylinders subject to external pressure and where the circumference has a flattened portion, it shall be demonstrated that the shell has sufficient strength to avoid plastic deformation where the depth of flattening is more than 0,4 % of the outside diameter of the cylinder. The depth of flattening shall be measured as a deviation from the normal curvature or from the line of the cylindrical shell. Adequate strength may be determined by calculation in accordance with formula (6) of 4.3.6.2.5, using a value of u determined as follows:

$$u = \frac{400}{D_a} q \qquad (36)$$

where

q is the depth of flattening, in millimetres;

D_a is the external diameter of the cylinder, in millimetres.

5.5.4.3 Departure of the cylinder axis from a straight line shall be not more than 0,5 % of the cylindrical length, except where required by the design.

5.6 Welding

5.6.1 General

This European standard requires that the welding method be appropriate and be carried out by qualified welders and/or operators, that the materials be compatible and that there is verification by a welding procedure test.

5.6.2 Qualification

Welding procedures shall be approved in accordance with EN 288-3, EN 288-4 or EN 288-8 as applicable.

Welders and welding operators shall be qualified in accordance with EN 287-1 or EN 287-2 or EN 1418 as applicable.

5.6.3 Temporary attachments

Temporary attachments welded to pressure bearing parts shall be kept to a practical minimum.

Temporary attachments welded directly to pressure bearing parts shall be compatible with the immediately adjacent material.

It is permissible to weld dissimilar metal attachments to intermediate components, such as pads, which are connected permanently to the pressure containing part. Compatible welding materials shall be used for dissimilar metal joints.

Temporary attachments shall be removed from the inner vessel prior to the first pressurisation. The removal technique shall avoid impairing the integrity of the inner vessel and shall be by chipping or grinding. Any rectification necessary by welding of damaged regions shall be undertaken in accordance with an approved welding procedure.

The area of the inner vessel from where the temporary attachments have been removed shall be dressed smooth and examined by appropriate non-destructive testing.

Any attachments on the outer jackets may be removed by thermal cutting as well as by the methods described above.

5.6.4 Welded joints

5.6.4.1 Some specific weld details appropriate to vessels conforming to EN 13458 are given in annex F. These details show sound and currently accepted practice. It is not intended that these are mandatory nor should they restrict the development of welding technology in any way.

The manufacturer, in selecting an appropriate weld detail, shall consider:

— the method of manufacture;

— the service conditions;

— the ability to carry out necessary non-destructive testing.

Weld details may be used provided their suitability is proven by procedure approval according to EN 288-3, EN 288-4 or EN 288-8 as applicable.

To avoid sub-standard welding of ferritic steels excess residual magnetism shall be avoided.

5.6.4.2 Where any part of a vessel is made in two or more courses, the longitudinal weld seams of adjacent courses shall be staggered. A minimum of 100 mm is recommended.

5.6.4.3 As the mechanical characteristics of work-hardened austenitic stainless steels can be adversely affected if the material is not welded properly, the additional requirements below shall be applied:

— the heat input during welding shall be not more than 1,5 kJ/mm per bead to be verified in the procedure qualification test ;

— the material shall cool down to a temperature of not more than 200 °C between passes;

— the material shall not be heat treated after welding;

See also B.2.7, B.2.8, B.2.10 and B.2.11.

5.7 Non-welded permanent joints

Where non-welded joints are made between metallic materials and/or non-metallic materials, procedures shall be established in a manner similar to that used in establishing welding procedures, and these procedures shall be followed for all joints. Similarly, operators shall be qualified in such procedures and only qualified personnel shall then carry out these procedures.

Brazing procedures and brazing approvals can be found in EN 13133 and EN 13134.

6 Inspection and testing

6.1 Quality plan

A quality plan shall include as a minimum, the inspection and testing stages listed in 6.1.1.

6.1.1 Inspection stages during manufacture of an inner vessel

The following inspection stages shall be conducted during the manufacture of an inner vessel:

— verification of material test certificates and correlation with materials;

— approval of weld procedure qualification records;

— approval of welders qualification records;

— examination of material cut edges;

— examination of set up of seams for welding including dimensional check;

— examination of weld preparations, tack welds;

— visual examination of welds;

— verification of non-destructive testing;

— testing production control test plates for welds and, where required, for formed parts after heat treatment;

— verification of cleaning of inside surface of vessel;

— examination of completed vessel including dimensional check;

— pressure test and where necessary record permanent set.

6.1.2 Additional inspection stages during manufacture of a static cryogenic vessel

The following inspection stages shall be conducted during the manufacture of a static cryogenic vessels:

— verification of cleanliness and dryness of static cryogenic vessel;

— visual examination of welds not covered by 6.1.1;

— ensure integrity of vacuum;

— leak test of external piping;

— check documentation and installation of pressure relief device(s);

— check installation of vacuum space relief device;

— check name plate and any other specified markings;

— examination of completed vessel including dimensional check.

6.2 Production control test plates

6.2.1 Requirements

Production control test plates shall be produced and tested for the inner vessel as follows:

a) one test plate per vessel for each welding procedure on longitudinal joints;

b) after 10 sequential test plates to the same procedure have successfully passed the tests, testing may be reduced to one test plate per 50 m of longitudinal joint for 9 % Ni and ferritic steels and to one test plate per 100 m for other metals.

Production control test plates are not required for the outer jacket.

The results of the tests shall be as follows:

— weld tensile test (T): R_{et}, R_m and A_5 of the test specimens shall normally not be less than the corresponding specified minimum values for the parent metal, or the agreed values of the welding procedure approved ;

— impact test (IW, IH): this test shall be performed in accordance with EN 1252-1 or EN 1252-2;

— bend test (BF, BR, BS): the testing and the test requirements shall comply with 7.4.2 of EN 288-3:1992 for steels and with 7.4.2 of EN 288-4:1992 for aluminium and its alloys ;

— macro etch (Ma): the macro etch shall show sound build-up of beads and sound penetration.