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**Alternative standard for construction
of pressure vessels**

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Foreword

This translation has been made based on the original Japanese Industrial Standard established by the Minister of Health, Labour and Welfare, and the Minister of Economy, Trade and Industry through deliberations at the Japanese Industrial Standards Committee according to the proposal of establishing a Japanese Industrial Standard from The High Pressure Gas Safety Institute of Japan (KHK)/Japanese Standards Association (JSA), with a draft of Industrial Standard based on the provision of Article 12 Clause 1 of the Industrial Standardization Law.

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Alternative standard for construction of pressure vessels

1 Scope

1.1 Pressure vessels within the scope This Japanese Industrial Standard applies to vessels whose design pressure is less than 100 MPa, whose design temperature is within the creep range, and that holds pressure exceeding the atmospheric pressure, or pressure vessels that experience external pressure (hereafter referred to as “pressure vessels”). This Standard does not include the following pressure vessels.

- a) Those that are included in the scope of other Japanese Industrial Standards⁽¹⁾
- b) Those that are nonmetallic
- c) Those that are related to atomic power
- d) Those that riveted or brazed
- e) Those that are exposed to direct fire
- f) Those that have special structures and uses⁽²⁾

Notes ⁽¹⁾ Examples are shown as follows.

Examples	JIS B 8201	<i>Stationary steel boilers —Construction⁽³⁾</i>
	JIS B 8240	<i>Construction of pressure vessels for refrigeration</i>
	JIS B 8241	<i>Seamless steel gas cylinders</i>
	JIS B 8265	<i>Construction of pressure vessel—General principles</i>
	JIS B 8501	<i>Welded steel tanks for oil storage</i>

- ⁽²⁾ Pressure compartments of rotating machines or reciprocating machines such as hydraulic machines, hydraulic presses, pumps, compressors, turbines, internal combustion engines, hydraulic cylinders, pneumatic cylinders.

- ⁽³⁾ Waste heat boilers are included in the scope of JIS B 8201 and are outside this Standard.

Remarks : This Standard include pressure vessels whose design pressure is less than 100 MPa, but it may be applied to those whose design pressure is 100 MPa or more, if special technical consideration is given to the following matters: materials used, internal and external surface finish (roughness) of pressure vessels, screws, non-destructive test, etc.

1.2 Range of pressure vessels

- a) The main body of pressure vessels (shells, heads, and nozzles that are directly connected thereto, etc.) and the following items 1) to 3) shall be included in the range to be considered as pressure vessels.
 - 1) At the connection to external pipes.
 - 1.1) As far as the first circumferential joint of weld joint (the groove face shall be included, but the weld joint is not included).
 - 1.2) As far as the first screw joint of the screw joint.
 - 1.3) As far as the first flange face of the bolted flange face.
 - 2) As far as the weld joint when attachments are directly welded to the pressure parts.
 - 3) For manholes, hand holes, etc, the cover plates, welded joints, bolts, nuts and gaskets that withstand pressure shall be included.
- b) Auxiliaries such as attachments, safety valves, etc. that are directly mounted to pressure parts are not included in the scope of pressure vessels, but they shall satisfy the corresponding provisions.

2 Normative references The standards mentioned in attached table 1.1 or parts thereof contain provisions which, through reference in this Standard, constitute provisions of this Standard. In addition to these normative references, attached table 1.2 shows, as reference standards, those standards that are not applied to this Standard but are related to construction of pressure vessels.

3 Definitions For the major terms used in this Standard, the definitions given in JIS B 0190 apply.

4 Clarification of application conditions

4.1 General matters When using this Standard, users and manufacturers shall consider the intended use, environment and design conditions of pressure vessels, conform to the following provisions of 4.2 and 4.3, and clarify that they comply with the application conditions of this Standard for pressure vessels within the respective range of responsibility.

4.2 Design specifications prepared by users of pressure vessels Users of pressure vessels (including agents who have been delegated by users) shall clarify the application conditions of this Standard, prepare the design specifications of users on their responsibility, and present them to manufacturers of pressure vessels.

These design specifications shall include the following items.

- a) The planned operating conditions⁽⁴⁾ or design conditions⁽⁴⁾ that become appropriate

basic data for selection of materials, design, machining, and test and inspection

- b) Presence or absence of corrosion or erosion, and values of corrosion allowance
- c) Indication whether lethal substances are handled or not
- d) Basic shape, basic dimensions, etc. of pressure vessels⁽⁵⁾
- e) Whether fatigue analysis is necessary or not (basic data to judge whether fatigue analysis is necessary or not, such as the result of such judgment or experiential data)
- f) Operating environment conditions
- g) Other informative items such as operating experience data

Notes ⁽⁴⁾ The planned operating conditions shall include the conditions to determine 6.1.1, heat transmission conditions, contents and their values of physical properties. The design conditions shall include the 6.1.2 Design pressure and 6.1.3 a) Design temperature (high-temperature side and low-temperature side).

⁽⁵⁾ They shall include dimensions such as diameter, length, etc., mounting positions and supporting methods of manholes, nozzles and measuring equipment, and other basic shape and dimensions.

4.3 Design documents prepared by manufacturers of pressure vessels Design documents prepared by manufacturers shall be as follows.

- a) Manufacturers of pressure vessels shall confirm that the users' design specifications meet the provisions of 4.2, prepare the design documents on their responsibility based on the user's design specification according to this Standard, and obtain users' approval.

Remarks : The design documents shall include specifications, drawings and design calculation sheets.

- b) The design documents shall include, in addition to calculation of wall thickness, evaluation by stress analysis and fatigue analysis mentioned in annex 8. However, if it is exempted by provisions of 6.4.2 or 6.4.3, then, such evaluation is not included.

5 Materials

5.1 Materials in general Materials of pressure parts used for pressure vessels based on this Standard shall be as follows.

- a) **Standard materials** The standard materials stipulated in this Standard shall be such materials as specified in JIS mentioned in attached table 2.1, attached table 2.2, attached table 3.1, and attached table 3.2.
- b) **Equivalent materials** If any materials are compared with the standard materials specified in attached table 2.1, attached table 2.2, attached table 3.1, and attached table 3.2, and if they meet either of the following items, then, they may be regarded

as the materials equivalent to the standard materials.

- 1) The standard material, chemical composition and mechanical property are the same. But, the tolerance of sheet thickness is slightly different.
 - 2) The standard material, chemical composition and mechanical property are the same. But, the manufacturing method or the shape is different.
 - 3) The standard material, chemical composition, mechanical property, test method and sampling method are very similar. The standard material and the said material are very similar in terms of properties.
- c) **Special certified materials** Even when materials are not specified in JIS, if they have been tested according to annex 10, and specially certified as appropriate as pressure vessel materials of this Standard by an agreement between the parties concerned with delivery; and even when materials are not specified in JIS mentioned in a) but are specified in ISO or other standards, if they have been confirmed and specially certified as having properties at least equivalent to the standard mentioned in a) by an agreement between the parties concerned with delivery; then, they may be used for pressure parts of pressure vessels.
- d) **Tolerance of material thickness** The tolerance of material thickness shall be as follows.
- 1) The material thickness shall be equal to or more than the design thickness.
 - 2) The sheet material may be used if the negative tolerance of thickness is 0.3 mm or 6 % of nominal thickness whichever is smaller.
 - 3) When pipes are used for pressure parts, the negative tolerance of thickness specified in JIS material standards shall be included in the count.
- e) **Working temperature range of materials** The standard materials specified in attached table 2.1, attached table 2.2, attached table 3.1, and attached table 3.2 shall not be used exceeding the maximum temperatures for which those tables show the design stress strength and allowable tensile stress. On one hand, the low-temperature working limit shall be as specified in 5.3.5 for steel and 5.4.1 for nonferrous metals.
- f) **Fatigue characteristics of materials** Design of pressure vessels shall consider fatigue characteristics of materials. When exemption of fatigue analysis in 6.4.3 is not applicable, only the materials whose fatigue characteristics curves are shown in annex 8 may be used. However, if sufficient data are available to draw the design fatigue curves, then, this provision does not apply.
- g) **Addition of inspection to JIS material standards** Some JIS material standards specify non-destructive test and special additional inspection that are designated by orderers. Manufacturers of pressure vessels shall comply with provisions of 5.3.4, 5.3.5 and 5.4.4 of this Standard, designate additional inspection, and order materials. Furthermore, the material certificate issued by material manufacturers shall show that the materials meet the provisions of applicable material standards

and other provisions including the additional inspection. This material certificate includes evidence of numerical results of all the necessary tests.

- h) **Limitation of materials used concerning contents** The materials used for pressure vessels holding corrosive substances shall be selected by considering, in advance, resistance to the contents.
- i) **Material classification** Material classification and group number in this Standard shall be as specified in JIS B 8285, attached table 1.
- j) **Heat-treated high tensile strength steel** This refers to such a steel that is heat-treated according to the process 3510 in JIS G 0203, has the property as high tensile strength, and whose minimum tensile strength is specified as 620 N/mm² or more.

Remarks : The examples of JIS standard materials that correspond to this heat-treated high tensile strength steel as follows.

SQV1B, SQV2B and SQV3B of JIS G 3120

SL5N590, SL9N520 and SL9N590 of JIS G 3127

SFVQ1B, SFVQ2B and SFVQ3 of JIS G 3204

STPL690 of JIS G 3460

STBL690 of JIS G 3464

5.2 Materials used for pressure vessels

5.2.1 Materials used for main body of pressure vessel The materials used for main body of pressure vessel shall be the steel materials mentioned in attached table 2.1, the nonferrous metal standard materials mentioned in attached table 2.2, the materials equivalent to these and specified in 5.1 b), or the special certified materials specified in 5.1 c).

5.2.2 Materials used for attachments and support structures Jackets, support structures, attachments and other parts that are directly welded to the main body of pressure vessel may be the standard materials mentioned in JIS B 8265, attached table 2.1.1 and attached table 2.2, or the materials that are equivalent to these, or the special certified materials. However, those welding materials used for welding to the main body shall be compatible with the material of pressure part of main body of pressure vessel. The weld joint shall meet the provision of this Standard.

5.2.3 Materials used for steel bolts If flanges, bolted cover plates and tube sheets are designed by stress analysis, then, the materials for steel bolts shall be the standard materials mentioned in attached table 3.1. If flanges are designed by annex 3, annex 4, annex 5 and annex 6, and if bolted cover plates are designed by annex 7, then, the materials for steel bolts shall be the standard materials mentioned in attached table 3.2. In both cases, the materials for steel bolts may be the materials that are equivalent to these and that are specified in 5.1 b).

5.3 Steel materials

5.3.1 Usage limitation in general of steel materials The usage limitation in general of steel materials shall be as follows.

- a) Carbon steel or low-alloy steel that contains carbon exceeding 0.35 % (cast analysis value) shall not be used for welded structures. If any JIS standard materials whose carbon content is not specified are used for welded structures, then, an order shall be placed by adding a special provision to limit carbon content 0.35 % or less. The material certificate shall describe the carbon content.
- b) The forging article that contains carbon exceeding 0.35 % (cast analysis value) shall not be used for welded structures. However, if small nonpressure attachments are welded according to the provision of annex 11, 2 b), note⁽¹⁾, or if the screw joints are seal welded, or if welding is performed only for repair, then, carbon content 0.5 % or less is allowable. The forging article that contains carbon exceeding 0.5 % shall not be used for any welding.
- c) The material used for pressure vessels shall be the killed steel.

5.3.2 Heat treatment of steel If the applicable material standard specifies that the ferrite system material shall be heat-treated either as rolled or after it is normalized, and if not otherwise specified, then, a special provision may specify, as necessary, that the material shall be normalized, normalized and tempered, or subjected to thermoforming control. The normalizing in this case shall include the accelerated cooling and subsequent tempering to enhance the tensile characteristics and impact property.

5.3.3 Sampling of test coupon and test specimen The test coupon and test specimen shall be sampled according to the following provisions. However, when an impact test is performed according to 5.3.5, the impact test specimen shall be sampled according to annex 15.

- a) **Definition of thickness** In the provision of 5.3.3, thickness shall be defined as follows.
 - 1) **Sheet** Dimension measured at right angle to the rolled surface.
 - 2) **Forged-steel article** Definition depends on its shape.
 - 2.1) **Hollow forged-steel article** Distance between an internal surface and an external surface (radial thickness).
 - 2.2) **Flat disk type forged-steel article** Length measured in the shaft direction. (Length in the shaft direction $\leq$ outside diameter).
 - 2.3) **Flat ring form forged-steel article** When the dimension of shaft direction is 50 mm or less, the thickness shall be the dimension of shaft direction. When the dimension of shaft direction exceeds 50 mm, the thickness shall be the dimension measured the radial direction. (when the length of shaft direction is smaller than the thickness in the radial direction).

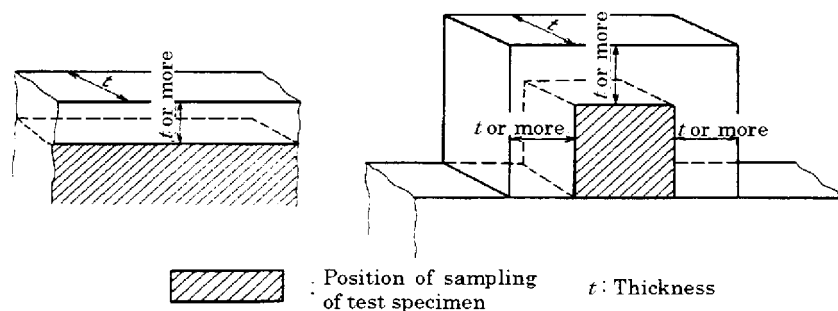
- 2.4) Forged steel article of a square cross section without a hole The length of the smaller side of cross section.
- 3) Cast steel article If a cast steel article is of the usual shape, it shall be handled in the same manner as a forged steel article.
- b) **Sampling of test coupon and test specimen of steel material** Sampling of test coupon and test specimen of steel material shall be as follows. However, when an impact test is performed according to 5.3.5, the impact test specimen shall be sampled according to annex 15.
 - 1) **Steel sheet** A steel sheet shall be as follows.
 - 1.1) The method for sampling of test coupon, the number of test specimens, and the sampling position shall be specified by the provisions of applicable material standard.
 - 1.2) When a test specimen is sampled from the steel sheet or test coupon that has been normalized (including accelerated cooling), normalized and tempered, or quenched and tempered, then, the procedure shall meet applicable material standard. The sampling position shall be far enough from the heat-treated edge by the distance that satisfies c) 3).
 - 1.3) When the hub for butt welding is machined out of a sheet for the flat head, the tube plate, the flange, etc., then, an additional test specimen shall be sampled from the position that is shown in attached figure 1 a) 1) to 3).
 - 2) **Steel pipe** A steel pipe shall be as follows .
 - 2.1) The method for sampling of test coupon, the number of test specimens, and the sampling position shall be specified by the provisions of applicable material standard.
 - 2.2) When a test specimen is sampled from the steel tube that has been normalized (including accelerated cooling), then, the procedure shall meet applicable material standard. The sampling position shall be far enough from the heat-treated edge by the distance that satisfies c) 3).
 - 3) **Steel bar and bolt material** The steel bar and bolt material shall be as follows.
 - 3.1) The provisions about the test specimen shall be as specified in applicable material standard. The sampling position shall be far enough from the material surface or the rolled surface by at least $\frac{1}{4}t$ (where t is the diameter or thickness of steel bar). At the same time, the end face of test specimen shall be far enough from the edge of the heat-treated steel bar by t . If sampling is impossible at the position of $\frac{1}{4}t$, then, sampling shall be performed at the position that is as close as possible.
 - 3.2) The test specimen of bolt material shall be sampled according to provisions of applicable material standard.
 - 3.3) When the bar steel or bolt material is heat-treated, then, sampling position

shall be far enough from the heat-treated edge by the distance that satisfies c) 3.1).

- 4) **Forged-steel article** A forged-steel article shall be as follows.
- 4.1) The method for sampling of test coupon, the number of test specimens, and the sampling position shall be specified by the provisions of applicable material standard and 4.2.2 of JIS G 0306.
- 4.2) A test specimen shall be sampled by either of the following methods.
- 4.2.1) In case of heat treatment where the cooling rate from austenitizing temperature is faster than furnace cooling, then, test specimen shall be sampled in parallel direction from the pads or excess of a forged-steel article toward the main forging direction. In this case, the centre of test specimen shall be far from one heat-treated surface of forged-steel article or material by $\frac{1}{4}T$ or more. At the same time, it shall be far from the second heat-treated surface by T or more. T is the maximum heat treatment thickness of a forged-steel article (it is the same hereafter.).
- 4.2.2) Nozzles, thick tube sheets, flanges and other forged-steel articles of complex shape are formed or machined into almost the shape of finished products before heat treatment. In this case, test specimen shall be sampled in parallel direction from the pads or excess of a forged-steel article toward the main forging direction. The sampling position shall be as far as possible from the heat-treated surface. The distance shall be whichever longer, either the distance to the predetermined high tensile surface, or the distance to the heat-treated surface that is closest to the former. At the same time, the sampling position shall be far from the second heat-treated surface by the distance that is longer, twice or more, than the above-mentioned distance. In any case, the test specimen shall be far from the first heat-treated surface by 20 mm or more, and far from the second heat-treated surface by 40 mm or more.
- 4.2.3) In the case of a flat ring and a simple ring-like forged-steel article, a test specimen may be sampled from another forged-steel material manufactured so that it satisfies the following conditions. The axis of test specimen shall be far from the first heat-treated surface by $\frac{1}{4}T$ or more. At the same time, it shall be far from the second heat-treated surface by T or more.
- 4.2.3.1) The test specimen shall have the same molten steel as the forged-steel article. The forging ratio shall be substantially the same. The hot work shall be of the same kind.
- 4.2.3.2) The test specimen shall be heat-treated in the same furnace and under the same conditions as the forged-steel article.
- 4.2.3.3) The test specimen shall have the same heat treatment thickness as the forged-steel article.

- 5) **Cast-steel article** A cast-steel article shall be as follows.
 - 5.1) The method for sampling of test coupon, the number of test specimens, and the sampling position shall be specified by the provisions of applicable material standard and 6.2.2 of JIS G 0307.
 - 5.2) In the case of normalizing (including accelerated cooling), normalizing and tempering, or quenching and tempering, a test specimen shall be sampled as follows.
 - 5.2.1) When the maximum thickness of a cast-steel article is 50 mm or less, a test specimen shall be sampled from test coupon according to applicable material standard.
 - 5.2.2) When the maximum thickness of a cast-steel article exceeds 50 mm, a test specimen shall be sampled from the cast-steel article itself or its excess. The longitudinal central axis of test specimen shall be far from the first heat-treated surface by $\frac{1}{4}T$ or more. At the same time, it shall be far from the second heat-treated surface by T or more. T is the maximum heat treatment thickness of a cast-steel article.
 - 5.2.3) A cast-steel article whose maximum thickness exceeds 50 mm is often cast or machined into almost the shape of finished products before heat treatment. In this case, test specimen shall be sampled from the pads or excess of a cast-steel article. The sampling position shall be as far as possible from the heat-treated surface. The distance shall be whichever longer, either the distance to the predetermined high tensile surface, or the distance to the heat-treated surface that is closest to the former. At the same time, the sampling position shall be far from the second heat-treated surface by the distance that is longer, twice or more, than the above-mentioned distance. In any case, the test specimen shall be far from the first heat-treated surface by 20 mm or more, and far from the second heat-treated surface by 40 mm or more.
 - 5.2.4) If an orderer approves in advance, a test specimen may be sampled from another cast test coupon that satisfies the following conditions. The test specimen shall be at the distance that is equal to or as close as possible to $\frac{1}{4}T$. At the same time, it shall be far from the second heat-treated surface by T or more.
 - 5.2.4.1) The test specimen shall have the same molten steel as the cast-steel article. The casting method shall be substantially the same as the product.
 - 5.2.4.2) The test specimen shall be heat-treated in the same furnace and under the same conditions as the cast-steel article.
 - 5.2.4.3) The test specimen shall have the same nominal thickness as the cast-steel article.
- c) **Heat treatment of test specimen** Heat treatment of test specimen shall be as follows.

- 1) When ferritic material is heat-treated, a test specimen shall be sampled from the material that has been heat-treated, unless otherwise specified.
- 2) When a test coupon is separated from the main body and then is heat-treated, the separated test coupon shall be heat-treated under the specified conditions. After that, a test specimen shall be sampled from this test coupon.
- 3) When heat treatment involves normalizing (including accelerated cooling), a test coupon shall be cooled at the same or lower rate of cooling compared with the main body of material. For that purpose, either of the following methods shall be used.
 - 3.1) A test specimen shall be sampled from the position that is far from the heat treatment edge of material or test coupon by the distance equal to or longer than the thickness of material or test coupon (a diameter or an opposite side distance, in case of bar material).
 - 3.2) A steel reinforcing plate shall be welded by partial joint penetration to the material edge from which a test specimen is sampled. This plate shall be as wide as the thickness of material to satisfy 3.1) (see figure 5.1).



a) When sampling from a main body b) When sampling from test coupon

Figure 5.1 The extraction point of test specimen

- 3.3) A heat shield or a heat insulator shall be used for the material edge from which a test specimen is sampled.
- 3.4) The cooling-curve data of material and a device that can adjust the cooling rate of test coupon shall be available. This device cools the test coupon. It shall keep the time and temperature difference within 20 s and 15 °C, respectively, compared with the cooling curve of the material.
- 4) In some cases, materials are subjected to clad or cladding by welding before they are rapidly cooled from austenitizing temperature or normalized. Before this heat treatment, a test coupon shall be subjected to clad or cladding by welding to an object whose thickness is equal to that of the main body.

- 5) When a test coupon is heat-treated correspondingly to the heat treatment of vessel after welding, the holding time shall be 80 % or more of the actual total holding time of heat treatment after welding. Then, a single continuous session is acceptable.

5.3.4 Non-destructive test of steel material The non-destructive test of steel material shall be performed according to provisions of JIS material standards, and also it shall be as follows.

- a) **Steel sheet** All the steel sheets whose nominal thickness exceeds 100 mm shall be tested ultrasonically. They shall conform to JIS G 0801 or JIS G 0802.
- b) **Forged-steel article** The ultrasonic test of a forged-steel article shall be as follows.
 - 1) All the forged-steel articles of the carbon steel and low alloy steel whose nominal thickness exceeds 100 mm shall be tested ultrasonically according to JIS G 0587. In this case, both the straight beam and angle beam techniques shall be applied to rigns, flanges, and other hollow forged-steel articles whose outside diameter is not more than 1.4 times the inside diameter. Only the straight beam technique shall be applied to other forged-steel articles. The stage and acceptance criterion of a ultrasonic test shall conform to the following provisions of 1.1) and 1.2).
 - 1.1) **Flaw-detection stage** Flaw shall be detected after final heat treatment (excluding the stage of straightening annealing), which is required to obtaining the necessary mechanical characteristics of a forged-steel article. Moreover, flaw shall be detected completely over the entire surface of a forged-steel article. However, if this is impossible because of the shape of a forged-steel article, then, flaw shall be detected before final heat treatment where the entire surface can be tested. Also in this case, a complete test shall be carried out after the final heat treatment by reaching the accessible surface.
 - 1.2) **Acceptance criterion** If they conform to Group 1, Group 2 and Group 3 mentioned in annex 1 table 1, and annex 1 table 2 of JIS G 0587, then, they shall be acceptable.
 - 2) All the stainless-steel forged-steel articles whose nominal thickness is 100 mm or more shall be tested ultrasonically. The test shall conform to annex of JIS G 3214. In this case, both the straight beam and angle beam techniques shall be applied to rigns, flanges, and other hollow forged-steel articles whose outside diameter is not more than 1.4 times of the inside diameter. Only the straight beam technique shall be applied to other forged-steel articles.
- c) **Clad steel** The joints of articles made of the stainless clad steel, the nickel and the nickel-alloy clad steel, the titanium clad steel, the copper, and the copper-alloy clad steel whose nominal thickness is 8 mm or more (including a cladding metal) shall be tested ultrasonically according to the provision clause 5 of JIS G 0601. They shall conform to Class 1, F, of table 3 mentioned in JIS G 3601, JIS G 3602, JIS G 3603, and JIS G 3604. The weld integrity of overlay-clad steel found by a ultrasonic test shall be subjected to the agreement between the parties

concerned with delivery.

d) **Cast-steel article** A cast-steel article shall undertake a radiographic examination or a ultrasonic test and a magnetic particle examination, or a liquid penetrant inspection by the test methods and test ranges which are shown below.

1) **Radiographic examination** A radiographic examination shall be applied to all the parts of a cast-steel article whose thickness is 300 mm or less. The test method shall conform to JIS G 0581. Flaws shall be judged as follows.

1.1) A crack, poor welding of core, and poor welding of enveloped casting are not acceptable.

1.2) A blowhole, sand inclusion, other inclusion, and shrinkage cavity are acceptable if they conform to the classification of table 5.1.

Table 5.1 Judgement classification of blowhole, sand inclusion, other inclusion, and shrinkage cavity

Classification of defect		Wall thickness of a test part	
		20 mm or less	above 20 mm
Blowhole		Group 1	Group 2
Sand inclusion and other inclusion		Group 1	Group 2
Shrinkage cavity	Linear	Group 1	Group 2
	Tree-like	Group 1	Group 2

2) **Ultrasonic test** The parts of a cast-steel article whose thickness exceeds 300 mm shall be tested ultrasonically, whenever possible, by straight beam technique. For the test, JIS Z 2344 applies, and the rest of conditions are as follows.

2.1) Flaw shall be detected after final heat treatment, which is required to obtain the necessary mechanical characteristics of a cast-steel article.

2.2) The surface of test part of a cast-steel article shall be free from a mill scale, sand, etc. in order not to disturb transmission of supersonic waves. The surface shall be made flat and smooth with sanding, machining operation, etc. if needed.

2.3) The diameter of a probe shall be 20 mm to 30 mm. However, probes of other diameters may be used, if needed.

2.4) A test frequency shall be 1 MHz. However, other frequencies may be used in order to presume the location, behavior, etc. of defects.

2.5) The reference test specimen used to adjust a working sensitivity shall have a composition that is equivalent to a cast-steel article. However, if it is confirmed that an ultrasonic attenuation factor is equivalent, then, specimens of other quality of material may be used.

The dimension of a reference test specimen shall be as specified in table 5.2 and figure 5.2. However, the reference test specimen 6-B shall be used for a working distance that exceeds 350 mm.

Table 5.2 Dimension and number of reference test specimens

Unit mm			
t	L	$W^{(7)}$	Number
25	45 ± 3	50 or more	6-025
50	70 ± 3	50 or more	6-050
75	95 ± 3	50 or more	6-075
150	170 ± 3	75 or more	6-150
250	270 ± 3	100 or more	6-250
$B^{(6)}$	$B \pm 20$	125 or more	6-B

Notes ⁽⁶⁾ B is thickness of a cast-steel article.

⁽⁷⁾ W is width or diameter.

Unit mm

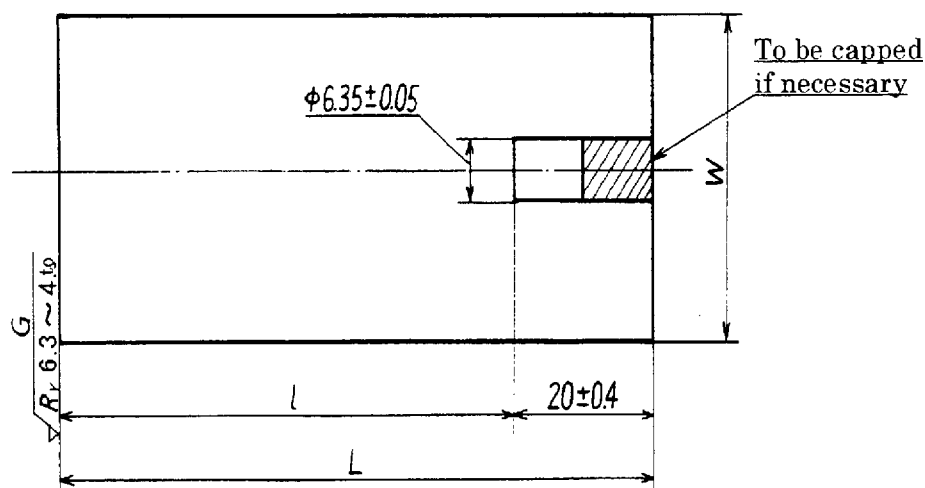


Figure 5.2 Reference test specimen

- 2.6) A working sensitivity shall be adjusted so that F echo through a flat bottom hole from the reference test specimen No. 6-250 may become 10 % of a scale plate. At this sensitivity, other reference test specimens are tested. The peaks of F echo from each hole shall be plotted to draw a reference line. When the wall thickness of a cast-steel article is over 250 mm up to and including 350 mm, a reference line shall be extended.

When the thickness of material exceeds 350 mm, a sensitivity shall be adjusted so that F echo height through a flat bottom hole from the reference test specimen No. 6-B may become 10 %, and a reference line shall be drawn.

Next, the following procedure is necessary. The surface roughness of a cast-steel article is different from the roughness of test surface of a reference test specimen. In order to compensate this difference, select one of test specimens that are closest to the thickness of a cast-steel article. Select the position of a flat bottom hole and side face that be least influenced. Then, obtain the height of bottom echo at the above-mentioned sensitivity. Place a probe on a cast-steel article. Make adjustment so that the height of bottom echo agrees with that of a reference test specimen. This shall be defined as a working sensitivity.

- 2.7) When the echo shown below is detected as a result of test, consider a path length, scan characteristics, etc., and judge whether the abnormal part is a defect or not. If it is judged as a defect, it is rejectable.
 - 2.7.1) Observe abnormal part showing echoes which go beyond the reference line. If its area exceeds 20 cm^2 , it is rejectable.
 - 2.7.2) Observe abnormal part showing echoes which go beyond the reference line. If its maximum length exceeds 65 mm, it is rejectable.
 - 2.7.3) Observe abnormal part showing echoes which go beyond the reference line. When two or more abnormal parts on the same plane, and if the mutual interval is smaller than the maximum length of the larger abnormal part, and if the area of these abnormal parts exceeds 20 cm^2 , then it is rejectable.
 - 2.7.4) If disappearance of bottom echo occurs in echos and it is not due to the shape of cast-steel article, it is rejectable. In this context, disappearance of bottom echo refers to the fact that the height of bottom echo becomes 5 % or less of a scale plate.
- 3) **Magnetic particle examination** The cast-steel article of a magnetic substance shall usually be tested by magnetic particle examination over the entire surface according to JIS G 0565.

Judgment of flaw shall be as follows according to indication of magnetic particles.

- 3.1) When a circular indication is present, if it conforms to the criteria shown in table 5.3, then, it is acceptable.
- 3.2) When a linear indication is present, if it conforms to the criteria shown in table 5.3, then, it is acceptable.

**Table 5.3 Maximum length or total length of a circular indication
and a linear indication**

Unit mm

Nominal thickness of a detection part	Maximum length or total length of indication
20 or lower	4
Over 20 to incl. 60	8
Over 60	16

3.3) When a distributed magnetic particle pattern is present, if it conforms to the total length of indication shown in table 5.3, then, it is acceptable.

- 4) **Liquid penetrant inspection** The cast-steel article of a nonmagnetic material shall be tested by liquid penetrant inspection for the entire surface according to JIS Z 2343-1 to 4 as much as possible.

Defects shall be judged according 3) 3.1) to 3.3) where magnetic indication should be read as liquid pattern. However, if any crack or hot tear is present, it is rejectable.

5.3.5 Impact test and minimum design metal temperature

- a) **The minimum design metal temperature of a pressure vessel** The minimum design metal temperature of a pressure vessel shall be the temperature which can permit the minimum metal temperature required for its design and manufacture. The requirement should be based on operation and environmental conditions of vessel (the minimum operating temperature, the abnormal condition at the time of operation, outdoor air temperature, other sources of cooling, etc.). Usually, this minimum metal temperature required shall be defined as the minimum design metal temperature. However, where an impact test is exempted by the temperature for the impact test or provisions in annex 15, if the temperature exempted is lower than this minimum metal temperature (the minimum design metal temperature) required, then, the minimum design metal temperature may be lowered by the agreement between the parties concerned with delivery.
- b) **Impact test** There are structural components of pressure vessel, such as shell, head, nozzle, manhole, reinforcement, flange, tube sheet, flat cover plate etc. There are also welded attachments to pressure holding structural components. These shall be handled as individual components respectively. Consideration shall be given to the type of individual material, thickness, the minimum design metal temperature required by a). Based on this consideration, the requirement for impact test shall be evaluated according to annex 15. An impact test shall be carried out below the minimum design metal temperature according to annex 15.
- c) **Special provision to the minimum design metal temperature and impact-test temperature** A special provision applies to the vessel manufactured by ferrous materials other than austenitic stainless steel as follows. However, when an impact test is exempted, the temperature exempted may be regarded as impact-test temperature.

- 1) The test temperature to the minimum design metal temperature at the time of the pressure resistance test of a pressure vessel shall be as specified in 11.6.1 a).
- 2) When the minimum design metal temperature is under $-10\text{ }^{\circ}\text{C}$, if postweld heat treatment is not applied to the nozzle mount welded part and other parts of high local stress, then, the impact-test temperature shall be set lower than the minimum design metal temperature by $17\text{ }^{\circ}\text{C}$. However, this does not apply to the 9 % nickel steel with thickness of less than 50 mm.
- 3) If the vessel is to contain the lethal substances, the impact-test temperature shall be set lower than the minimum design metal temperature by the following values of temperatures.

Nominal thickness	25 mm or less	0 $^{\circ}\text{C}$
	Over 25 mm to and incl. 50 mm	11 $^{\circ}\text{C}$
	Over 50 mm to and incl. 75 mm	22 $^{\circ}\text{C}$
	Over 75 mm	33 $^{\circ}\text{C}$

5.4 Nonferrous metals

5.4.1 The minimum design metal temperature Materials shall not be used below the minimum design metal temperature shown for each material shown in table 5.4.

Table 5.4 Minimum design metal temperature of nonferrous metals

Material classification	Copper and copper alloy	Nickel and nickel alloy	Aluminium and aluminium alloy	Titanium and titanium palladium alloy	Nickel ferrochromium alloy
Minimum design metal temperature	$-269\text{ }^{\circ}\text{C}$				$-196\text{ }^{\circ}\text{C}$

5.4.2 Sampling of test coupon and test specimen The sampling of test coupon and test specimen shall be as specified in applicable material standards.

5.4.3 Heat treatment of test coupon The heat treatment of test coupon shall be as follows.

- a) The test coupon representing the component which receives heat treatment during manufacture of a pressure vessel shall be heat-treated according to the heat-treating conditions applied to a pressure vessel. In this case, heat-treating conditions shall be arranged by consultation between the parties concerned with delivery. The heating rate, the holding time of heat-treating temperature, and the cooling rate shall represent the heat-treating conditions applied to a pressure vessel.
- b) If the test coupon from which the test specimen is sampled does not come from the main body, then, the test coupon shall be large enough to represent the cooling rate of the material used for manufacture of a pressure vessel.

- c) In any case, the dimensions (length, width, thickness) of test coupon shall be $3t \times 3t \times t$ or larger. Where, t is nominal thickness. Moreover, the sampling position of test specimen shall be far from any edges of test coupon by t or more.

5.4.4 Non-destructive test of nonferrous metals The non-destructive test of nonferrous metals shall be performed according to JIS standard material, and also it shall be as follows.

- a) **Plate** The plate whose nominal thickness exceeds 100 mm shall be subjected to the following ultrasonic test.
- 1) The straight beam technique shall be used.
 - 2) A probe shall be round with diameter of 20 mm to 30 mm, or square with one side of 25 mm.
 - 3) A test frequency shall be appropriate according to the type of material.
 - 4) A working sensitivity shall be adjusted so that the height of the first echo from defect-free portion of material may be 80 % of Braun-tube scale height.
 - 5) If disappearance of bottom echo occurs in echos and it is not due to the shape of plate, it is rejectable. In this context, disappearance of bottom echo refers to the fact that the height of bottom echo becomes 5 % or less of a scale plate.
- b) **Forged article** The forged article whose nominal thickness exceeds 100 mm shall be subjected to the following ultrasonic test.
- 1) A square forged-type block shall be tested by the straight beam technique. In this case, the beam should be applied from two directions that are orthogonal.
 - 2) Flanges, ring-shaped articles, and other hollow forged article shall be tested, in addition to 1), by the angle beam technique. This technique employs a direct contact method, a water-immersion method, or a local water-immersion method. These hollow forged articles shall be tested from one plane perpendicular to an axis and from the circumferential direction. This provision does not apply when the angle beam technique is difficult because of the thickness or shape of articles.
 - 3) Flat disk type forged articles shall be tested both from one plane and from the circumferential direction.
 - 4) The forged articles shall be tested, during either manufacturing stage, to detect flaws for the entire volume of material. The heat-treated materials should be tested completely after final heat treatment. If this is impossible because of the shape, the accessible range shall be retested after the final heat treatment.
 - 5) The straight beam technique shall be as specified in a) 2) to 5).
 - 6) The angle beam technique by direct contact method shall be used a 45-degree transducer of 25 mm $\times$ 25 mm or 25 mm $\times$ 38 mm. Frequencies shall be appropriate depending on materials.

- 7) The angle beam technique by water-immersion method or local water-immersion methods shall be used a transducer of 19 mm in diameter. Angles of refraction and frequencies shall be appropriate depending on materials.
- 8) The angle beam technique shall be adjusted using the notch of the following dimensions. The depth is whichever smaller, either 9.5 mm or 3 % of the nominal thickness of the material to be tested. The length is about 25 mm. The width is not more than twice the depth.
- 9) When one or more defects are found in the angle beam technique, if the echo is larger than the echo from the reference test specimen notch, then, it is rejectable.

5.5 Bolts, nuts, and washers The bolts (including studs), nuts, and washers used for flanges and other attachable or detachable components shall be as specified in the relevant JIS for bolts, nuts or screws. In addition, they shall be as follows.

- a) A visual inspection shall be conducted about each part of screws, axes, hexagon heads after final machining. If they have lap, seam, crack and other defects, they are rejectable.
- b) The bolts and nuts whose nominal diameter exceed 50 mm shall be tested by a magnetic particle examination or a liquid penetrant inspection. If the line defect is found in a different direction from shaft orientations, then, it is rejectable. Moreover, if the line defect of the shaft orientations exceeds 25 mm, it is rejectable.
- c) The washers whose hardness is equivalent to the nuts of carbon steel or low alloy steel may be used at the metal temperature 480 °C or lower.
- d) When the metal temperature exceeds 480 °C, the nuts and washers of low alloy steel shall be used.
- e) The nuts (a box nut is included) shall fit over the entire length of screw.
- f) The dimensions of nuts shall be at least Style 2 specified in JIS B 1181.

6 Design

6.1 General design

6.1.1 Load to consider for design In design, consideration shall be given at least to the loads mentioned in the following a) to h). Each loading condition of design load, operating load, and test load shall be considered. The most unfavorable combination of loads that acts simultaneously shall be considered to design pressure vessels.

- a) The internal and external pressures including water head
- b) Tare of a vessel, and mass of the contents at the time of test and operation
- c) The load added (for example, mass of auxiliary equipment and device, auxiliaries, operation instrument, heat insulating material, lining against corrosion or erosion, piping, etc.)
- d) A wind load, a snow load, and a seismic load

- e) Reaction force of a lug, a ring, a saddle, and other types of support
- f) An impact load including a rapid pressure variation
- g) Load due to distortion difference caused by temperature conditions; reaction force of expansion and contraction of the mounted piping or other auxiliaries
- h) Repetitive load due to pressure or temperature change, or from other equipment; dynamic load and mechanical load

Remarks It is not necessary to combine a seismic load and a wind load simultaneously.

6.1.2 Design pressure For a design pressure, the following matters shall be considered.

- a) A design pressure shall be determined to withstand the most unfavorable conditions in relation to the operating pressure and operating temperature at each operating mode.
- b) At the conditions of a), consideration shall be given to the maximum pressure difference that is encountered between inside and outside of pressure vessel, or that is caused mutually between different chambers for a vessel consisting of plural chambers.

6.1.3 Design temperature For a design temperature, the following matters shall be considered.

- a) Two design temperatures shall be set; one is for high temperature side (to be called the design temperature), and another is for low temperature side (to be called the minimum design metal temperature).
- b) A design temperature shall be higher than the average temperature in the wall thickness direction of material at each operating temperature. However, in any case, the design temperature shall not exceed the maximum allowable range of working temperature that is specified in 5.1 e). Moreover, the design temperature of the pressure vessel that receives an external pressure shall not exceed the maximum temperature shown in the working temperature limit shown in the figure of the external pressure curves, and in Remarks of each curve that are mentioned in annex 1 attached figure 2.
- c) If the temperature decreases as a result of normal operation, abnormal operation, rapid decrease of pressure during operation, influence of atmospheric temperature with pressure being held, then, the annual lowest value of daily average temperatures shall be considered as the minimum design metal temperature. However, if the annual lowest value of daily average temperature is $-10\text{ }^{\circ}\text{C}$ or higher, then, an atmospheric temperature need not be considered.
- d) If different temperatures have been set for each part of a pressure vessel, then, a design temperature shall be determined for each part.

- e) The temperature of material shall be determined in two ways. Obtain it from the thermal rating formula that is formally recognized as necessary. Alternatively, mount a thermometer (thermocouple, thermistor, etc.) to the existing similar pressure vessels in operation under the same working conditions, and measure the temperatures of content and material.
- f) If temperatures change rapidly and periodically during normal operation where pressure fluctuation is almost non-existent, then, the maximum temperature (the minimum temperature for the case of low temperatures) and the pressure at that moment shall be used for design.

6.1.4 The minimum limitation thickness When the plate is used for a pressure part, it shall have the following minimum limitation thickness. The thickness that is measured after forming and that does not include the corrosion allowance shall be above this minimum thickness. However, this does not apply to the bellows type expansion joint, the heat-conduction sheet of plate type heat exchanger, and the heat exchanger tube whose nominal diameter is 6B or less.

- a) For carbon steel and low alloy steel, the minimum thickness shall be 6 mm.
- b) For high alloy steel and nonferrous metal, the minimum thickness shall be 3 mm.

6.1.5 Corrosion allowance A corrosion allowance and a wear allowance (hereafter referred to collectively as corrosion allowance) shall be as follows.

- a) In order to obtain thickness of the part of pressure vessel where corrosion or wear (referred to as corrosion) is likely occur, a corrosion allowance shall be added to the thickness obtained by calculation.
- b) If it is likely that different parts of pressure vessel have different degree of corrosion, then, it is not necessary to apply the same corrosion allowance to all the parts of vessel.
- c) When a pressure vessel made of carbon steel or low alloy steel is used for compressed air, steam, or water, the corrosion allowance of at least 1 mm shall be added. However, the heat exchanger tube does not need a corrosion allowance.
- d) Except the case of c), if the experience of similar service condition indicates absence of corrosion or presence of corrosion only on the surface, then, a corrosion allowance is not required.
- e) If corrosion and other damages are not foreseeable, a vessel shall be so structured as to facilitate inspection of parts where damages are likely to occur.
- f) The dimension notation used for design calculation in this Standard and the related JIS shall be construed the dimension without corrosion allowance, unless otherwise specified.

6.1.6 Compound vessel A compound vessel shall be as follows.

- a) It is a pressure vessel with two or more independent pressure chambers (each of which is so constructed as to independently withstand a pressure test and a leakage

test). Each chamber is operated at the same or different pressure and temperature. Accordingly, each chamber shall be so constructed as to withstand the most unfavorable combination of foreseeable pressure and temperature.

- b) A compound vessel may consists of pressure chambers that have been designed and manufactured according to respective provisions in this Standard and JIS B 8265. In that case, the connecting joint between two chambers shall conform to the provision of standard that stipulates higher severity.

6.1.7 Clad steel In case of clad steel, the formula mentioned in e) can be used to include a cladding metal or a cladding-by-welding part in calculation of strength. However, this is limited to the vessel that meets all the conditions mentioned in the following a) to d).

- a) The cladding metal meets the provision of 5.1 or the cladding by welding is performed according to the provision of 9.4.
- b) A butt weld joint is carried out by welding the anti-corrosion metal on the weld of a base material. It has the same composition as the cladding metal or a cladding-by-welding part.
- c) A clad steel is JIS standard material specified by the following standards or equivalent material.
 - 1) Class 1, F of JIS G 3601
 - 2) Class 1, F of JIS G 3602
 - 3) Class 1, F of JIS G 3603
 - 4) Class 1, F of JIS G 3604
- d) In a clad steel, the ratio of design stress strength between a cladding metal or a cladding-by-welding part and a base material is 0.7 or more.
- e) The following formula is used to calculate when a cladding metal or a cladding-by-welding part is included in calculation.

$$\sigma = \frac{\sigma_b t_b + \sigma_c t_c}{t_b + t_c}$$

Where, σ : The design stress strength of the clad steel at the design temperature (N/mm²)

σ_b : Design stress strength of a base material at the design temperature (N/mm²)

σ_c : Design stress strength of a cladding metal or a cladding-by-welding part at the design temperature of (N/mm²). In the case of an overlay clad, the value of the nearest material of chemical composition shall be used for the cladding-by-welding part.

t_b : Nominal thickness of a base material (mm)

t_c : The nominal thickness of a cladding metal, or the thickness of a cladding-by-welding part from which the corrosion allowance has been subtracted (mm)

However, if the design-stress strength of a clad steel or a cladding-by-welding part is larger than that of a base material, then, the design-stress strength of a clad steel shall use that of a base material.

6.1.8 Lining The thickness of lining shall not be included, even partly, in calculation of strength of a pressure vessel.

6.1.9 Telltale hole A telltale hole shall be as follows.

- a) A telltale hole shall be installed in a plate or a ring that is welded for reinforcement. A telltale hole shall be provided with the plug mounting screw where the nominal diameter of tube is $\frac{1}{4}B$ or less.
- b) A telltale hole may be installed in order to check that the thickness of a body shell plate has reduced to the dangerous level. A telltale hole shall be 4.5 mm or less in diameter. Its depth shall be 80 % or more of the thickness calculated for the seamless shell of the same dimension. It shall be bored from the side opposite to the surface that is subject to wear-out.

When a telltale hole is installed in the pressure vessel having a clad or lining, the depth of a hole may reach a cladding metal (or cladding-by-welding part) or a lining material.

When a telltale hole is installed in the pressure vessel holding lethal substances, an action shall be taken to prevent the leaked liquid from flowing out to atmospheric air.

6.1.10 Drain hole One drain hole shall be installed in the shell of a pressure vessel vulnerable to corrosion, or to the bottom head of longitudinal vessel. It shall be installed at the lowest position possible. When a riser tube is installed instead of a drain hole, the space between the opening of a riser tube and the lowest part of a pressure vessel shall be 6 mm or less.

6.1.11 Holes required for inspection, etc. Holes required for inspection, etc. shall be as follows.

- a) A pressure vessel shall be provided with holes required for examination, repair, and cleaning. However, this does not apply to the following pressure vessels.
 - 1) The inside diameter of shell is 300 mm or less.
 - 2) The inside diameter of shell is 500 mm or less. It has two or more detachable nozzles of nominal diameter of $1\frac{1}{2}B$ or more.
 - 3) The heads, cover plates, etc. are detachable. The heads, cover plates, etc. are larger than the holes specified in b).

- 4) The construction is corrosion-proof and air-tight. It has two or more detachable nozzles of nominal diameter of $1\frac{1}{2}B$ or more.
 - 5) It is an heat exchanger or other type of pressure vessel. In relation to its construction, shape or intended use, it does not require holes for inspection, repair, cleaning, etc.
- b) The number and dimension of a hole mentioned in a) depend on the inside diameter of shell, and they shall be as follows. However, if a hole is elliptical or oval, the ratio of major axis to minor axis shall be 1.5 or less.
- 1) When the inside diameter of shell is over 300 mm up to and including 500 mm, two or more holes shall be provided. One or more of them shall be an ellipse with major axis of 75 mm or more and minor axis of 50 mm or more, or a circle with diameter of 75 mm or more.
 - 2) When the inside diameter of shell is over 500 mm up to and including 1000 mm, one hole shall be provided. This shall be an ellipse with major axis of 375 mm or more and minor axis of 275 mm or more, or a circle with diameter of 375 mm or more, or an oval with major axis of 400 mm or more and minor axis of 270 mm or more. It shall be a manhole. This provision does not apply when two or more holes are provided, and when one or more of them are an ellipse with major axis of 90 mm or more and minor axis of 70 mm or more, or a circle with diameter of 90 mm or more.
 - 3) When the inside diameter of shell is over 1 000 mm, one or more manholes specified in 2) shall be provided.

6.2 Design-stress strength of material used for design, and tolerance limit of stress intensity

6.2.1 Design-stress strength The design-stress strength S_m at the design temperature is a basis to determine tolerance limit of various stresses caused by combination of various loads specified in 6.1.1. It shall be as follows.

- a) The design-stress strength at the design temperature shall be as follows. However, if a vessel is used at the temperature range lower than that each attached table shown below, then, it is possible to use, without any modification, the design-stress strength that corresponds to the minimum temperature shown in the attached tables.
 - 1) The design-stress strength of steel material shall be the value shown in attached table 2.1.
 - 2) The design-stress strength of nonferrous metals shall be the value shown in attached table 2.2.
 - 3) The design-stress strength of the bolt material of bolt applied to design by the stress analysis shall be the value shown in attached table 3.1.
 - 4) The permissible tensile stress of the bolt material of bolt applied to design without the stress analysis shall be the value shown in attached table 3.2.

- b) The setting criteria of the design-stress strength of material shall be as follows.
- 1) The setting criteria of the design-stress strength of the JIS material in attached table 2.1 and attached table 2.2 shall be as specified in clause 2 of annex 9.
 - 2) The design-stress strength of the JIS bolt material in attached table 3.1 and attached table 3.2, and the setting criteria of a permissible tensile stress shall be as specified in clause 3 of annex 9.
 - 3) The setting criteria of the design-stress strength of an equivalent material shall be the same as the design-stress strength of standard materials that are considered to be equivalent.
 - 4) The working temperature limits and the setting criteria of design-stress strength of a special certified material shall be as follows.
 - 4.1) The working temperature limits shall be the limits that have been confirmed by the property and performance qualification test according to annex 10.
 - 4.2) The setting criteria of the design-stress strength of steel material and nonferrous metal material shall be calculated according to clause 2 of annex 9. This calculation needs the tensile strength and yield point or 0.2 % proof stress that have been confirmed in the working temperature limits confirmed in 4.1).
 - 4.3) The setting criteria of the design-stress strength of a bolt material of special certified material shall be calculated according to clause 3 of annex 9.
- c) The design-stress strength at the design temperature of steel material and nonferrous metal material are not specified by provisions in a) 1), a) 2), b) 3), and b) 4.2). If the flange is designed by annex 3, annex 4, annex 5, or annex 6, and if the bolted cover plate is designed by annex 7, and if the disk type flat heads are designed by annex 1, then, the materials used or equivalent materials shall use the following values of the permissible tensile stress. This provision is valid even when the materials are mentioned in attached table 2.1 or attached table 2.2. They are mentioned in attached table 2.1.1 or attached table 2.2 of JIS B 8265. If the special certified materials are used, the values confirmed like b) 4.2) shall be used. The permissible tensile stress shall be set as follows.
- 1) The permissible tensile stress at each temperature above ordinary temperature shall be the minimum or less among the following values.
 - 1.1) 1/4 of the normal minimum tensile strength at ordinary temperature
 - 1.2) 1/4 of the tensile strength at each temperature
 - 1.3) The yield point or 1/1.5 of 0.2 % proof stress at ordinary temperature
 - 1.4) The yield point or 1/1.5 of 0.2 % proof stress at each temperature
 - 2) The permissible tensile stress at the design temperature below ordinary temperature shall be lower than whichever smaller, either the value in the above 1.1) or 1.4).
- d) Concerning the design-stress strength in attached table 2.1 and attached table 2.2,

some austenitic stainless steel materials and nonferrous metal materials exceed 1/1.5 of 0.2 % proof stress, reaching 90 %. This corresponds to the stress that causes the 0.1 % permanent distortion. If this deformation cannot be admitted, the design-stress strength should be lowered in order to have acceptable distortion. When the permanent deformation should be limited, the design-stress strength shall be calculated by multiplying the 0.2 % proof stress shown in attached tables 5.2 to 5.5 by the factor shown in table 6.1. However, if the design-stress strength in attached table 2.1 and attached table 2.2 is smaller than this value, then, the smaller one shall be used.

Table 6.1 Factor used to limit permanent distortion of high alloy steel, nickel, and high nickel alloy [†]

Permanent distortion to be limited %	Factor
0.10	0.90
0.09	0.89
0.08	0.88
0.07	0.86
0.06	0.83
0.05	0.80
0.04	0.77
0.03	0.73
0.02	0.69
0.01	0.63

6.2.2 Tolerance limit of various stresses The tolerance limit of various stresses shall be as specified in provisions of 2.3 and 2.4 of annex 8.

6.2.3 Permissible compression stress to shaft-direction compressive load The permissible compression stress at the design temperature shall be as follows.

- The permissible compression stress to shaft-direction compressive load shall be the same value as the design-stress strength. However, it shall not exceed the *B* value specified in b).
- The *B* value is calculated in the following procedure.

Procedure 1 Calculate *A* by the following formula.

$$A = \frac{0.125}{(R_o / t)}$$

Where, *t*: The estimated thickness is calculated by subtracting the corrosion allowance of the cylindrical shell or tube (mm)

R_o: The outside radius is calculated by subtracting the corrosion allowance of the cylindrical shell or tube (mm)

Procedure 2 Refer to annex 1 attached figure 2, and select the figures that correspond to the material used. In that figure, plot the value of A obtained by Procedure 1

- 1) Draw a vertical line from this point toward an axis of abscissa. Find the intersection with the temperature curve of the material that corresponds to the design temperature. When there is no temperature curve that corresponds to the design temperature, use an interpolation and find an intersection.
- 2) If the value of A is located farther to the right from the rightmost end of the temperature curve of material, then, extend the curve horizontally from that end, and find an intersection by operation of 1).
- 3) Draw a horizontal line from the intersection found in operation of 1) or 2). Find an intersection with the axis of ordinate on the left-hand side of the figure. Read the value of B .
- 4) If the value of A is located in the left side of the temperature curve of material, use Procedure 3.

Procedure 3 In the case of Procedure 2, 4), calculate B as follows.

$$B = \frac{AE}{2} \text{ (N/mm}^2\text{)}$$

Where E : Longitudinal elastic coefficient at the design temperature of material (N/mm²)

Procedure 4 The value of B is obtained from t and R_0 used. If this value is smaller than the calculated compressive stress of the shaft direction of cylindrical shell or tube, then, increase the thickness t and calculate B again. Repeat this step until the value of B exceeds the calculated compressive stress.

6.2.4 Premium of the design-stress strength to a primary membrane stress The premium of the design-stress strength is necessary for a seismic load or a wind load, and pressure test. The premium shall be as follows, unless specified by the related laws.

- a) If a primary membrane stress is caused when a seismic load or a wind load is combined with the loads specified in 6.1.1 a) to c), then, the design stress strength may be increased according to the provision of annex 8 table 3.
- b) The premium of the design-stress strength in a pressure resistance test (hydraulic test, pneumatic test) shall be as specified in annex 8 table 3.

6.3 Various characteristics of the material used for design Various characteristics of the material used for design shall be as follows. However, the following values of characteristics may be used only when design calculation is performed according to the provisions of this Standard.

- a) The longitudinal elastic coefficient at each temperature of material shall be as specified in attached table 4.1.
- b) The coefficient of linear expansion of material shall as specified in attached table 4.2.
- c) The yield point or 0.2 % proof stress of steel material (except for stainless steel) shall be as specified in attached table 5.1.
- d) The yield point or 0.2 % proof stress of stainless steel shall be as specified in attached table 5.2.
- e) The yield point or 0.2 % proof stress of stainless steel cast steel shall be as specified in attached table 5.3.
- f) The yield point or 0.2 % proof stress of nickel ferrochromium alloy shall be as specified in attached table 5.4.
- g) The yield point or 0.2 % proof stress of a nonferrous metals shall be as specified in attached table 5.5.

6.4 Stress analysis and fatigue analysis

6.4.1 Stress analysis and fatigue analysis of pressure vessel In some cases, this Standard lacks sufficient provisions that apply to a pressure vessel or parts thereof. In other cases, even when such provisions are available, designers or users of a pressure vessel want to select a design method based on stress analysis and fatigue analysis. In such cases, consideration shall be given to all the loads specified in user's design specifications. The pressure vessel or parts thereof shall be subjected to stress analysis and fatigue analysis as follows. However, when analysis is exempted by provision of 6.4.2 or 6.4.3, stress analysis or fatigue analysis of that part may be omitted.

- a) Stress analysis and fatigue analysis shall be performed according to the provision of annex 8. The tolerance limit of a stress shall not be exceeded. Jackets, support structures, attachments, etc. produce stress at a pressure part. Such stress shall be within the tolerance limit of the stress specified in annex 8.
 - b) Even when stress analysis and fatigue analysis are performed, the thickness of a pressure vessel shall be above the value calculated by the formula in the design method of shell and head specified in annex 1. However, this does not apply to the local range specified in the following 1) and 2).
- 1) If stress analysis can prove that a provision of 2.3 b) of annex 8 is satisfied, then, the thickness of a pressure vessel may be thin in a local range. The local range of a cylindrical shell, a spherical shell, or a conical shell shall be a surface area within a circle of diameter of $1.0\sqrt{Rt}$. The required distance to the adjoining local ranges that exist in all the directions of a shell surface shall be at least $2.5\sqrt{Rt}$.

Where, R : Inside radius of a shell (mm)

t : Required thickness of a shell (mm)

- 2) The thin local range exceeding the limit of 1) may be evaluated for stress by the provision of 2.5 of annex 8.

6.4.2 Exemption of stress analysis A pressure vessel that meet the following provisions of a) to f) is exempted from stress analysis by the stress-analysis method specified in provision of annex 8. However, when fatigue analysis is required and the stress analysis is required by this Standard, it is not exempted.

- a) When each part of a pressure vessel is designed according to various design calculation formulae and calculation methods specified in provisions of 6.5, 6.6, 6.7, 6.9 and 6.15, exemption is given to stress analysis of the load specified in those calculation formulae or calculation methods.
- b) The butt weld joint of the components with the same thickness.
- c) In performing the butt weld joint of the components whose thickness differs, if provisions of 7.2.1 a) to e) are satisfied, exemption is given. However, in the case of 7.2.1, e) 2), the following d) shall apply.
- d) This provision applies to the weld joint between the disk-type or semiellipsoidal head and the shell. The length of the flange part of head is $\sqrt{Rt}$. If the thickness of head sheet is different from that of shell, exemption is given to the weld joint with further taper of 3 : 1 or more. Here, notations R and t shall be as specified in 6.4.1.
- e) Joints made of a combination of different kinds of materials (including welding materials) that meet either of conditions 1) to 3) are exempted.
 - 1) The circumferential joint which satisfies all of the following 1.1) to 1.3).
 - 1.1) When the materials with different thickness is joined, the material that has higher design-stress strength is tapered or clad by welding.
 - 1.2) There is no discontinuity except difference in thickness and elastic coefficient.
 - 1.3) This formula $S_2 \leq 1.2S_1 \left(\frac{E_2}{E_1} \right)$ is valid.
 Here, subscripts ₁ and ₂ show the lower and higher values of design-stress strength, respectively. S is the design-stress strength. E is the longitudinal elastic coefficient.
 - 2) Mounting joints are exempted, when the materials of nozzle which reinforce holes meet the provision 3.5 of annex 2.
 - 3) Weld joints that are other than 1) and 2), and that meet all of the following 3.1) and 3.2).
 - 3.1) Since the thickness of the component to join differs, in attaching a taper required for a connector part, the taper is attached to the material of which design-stress strength is higher, or it is attached by the adequate cladding by welding for the material of which design-stress strength is higher.
 - 3.2) This formula $S_2 \leq 1.2S_1 \left(\frac{E_2}{E_1} \right)$ is valid.
 Here, subscripts ₁ and ₂, and symbols S and E mean the same as in 1.3).

- f) If the part of the said pressure vessel to be subjected to stress analysis is similar to the past product in terms of shape and load conditions, and if the past operation experience or analysis data prove that the provisions in annex 8 are satisfied, then, analysis is exempted.

6.4.3 Exemption of fatigue analysis If the conditions specified in the following a) to c) are satisfied, then, fatigue analysis of that part may be exempted.

- a) **Operation experience and conditions to determine whether fatigue analysis is necessary or not** When users determine whether fatigue analysis of a pressure vessel is necessary or not, if they consider the similar design and past experience of similar operation of comparable vessel, and they can prove that fatigue analysis is not necessary, then, analysis is exempted. However, if hazardous results are foreseeable because of the following design structures, then, special study shall be made.
- 1) Plate-type reinforcement, fillet welding attachments, and other non-solid structures
 - 2) Joints using tube screws. Especially the joints with diameter of above 70 mm
 - 3) Studded or bolted attachments
 - 4) Partial joint-penetration weld
 - 5) The part where thickness of main sheets changes between adjacent components
- b) **Conditions to determine fatigue analysis of solid parts of pressure vessel is necessary or not** If the solid parts of pressure vessel meet either all the conditions A in 1) or all the conditions B in 2), then, fatigue analysis is not necessary.
- 1) **Conditions A** The case when steel materials are mentioned in attached table 2.1; their specified minimum tensile strength is 550 N/mm² or less; and the total repetitive number of times from 1.1) to 1.4) is 1 000 or less.
 - 1.1) The estimated (design) repetitive number of times of pressure cycle over the entire range, including start and stop.
 - 1.2) The estimated repetitive number of operative pressure cycles where pressure fluctuates over 20 % of the design pressure. (Pressure fluctuation due to a change open air conditions need not be considered.)
 - 1.3) The effective repetitive number of times of metal temperature fluctuation between two adjacent points⁽⁸⁾ of pressure vessel including the nozzle. The repetitive number of times of metal temperature fluctuation is multiplied by the following factors. The results shall be summed up.

Metal temperature fluctuation °C		Factor
	25 or less	0
over 25	to and incl. 50	1
over 50	to and incl. 100	2
over 100	to and incl. 150	4
over 150	to and incl. 200	8
over 200	to and incl. 250	12
over 250		20

Note (8) The distance between the two adjacent points means the following.

a) For the temperature difference on metal surface

1) For the direction of the meridian of shell and disk type head

$$L = 2.5\sqrt{Rt}$$

2) For flat plate

$$L = 3.5a$$

Where, L : The shortest distance between adjacent points (mm)

R : Radius from the centre of thickness to a revolving shaft that is measured perpendicularly to the material surface (mm)

t : Thickness of the component in the considered point (mm)

a : Radius of hot spot on a sheet or heated area (mm)

When the values of Rt of two points differ, the average value of the values at the two points shall be used.

b) For the temperature gradient of wall-thickness direction, it refers to the distance between any two points on a line perpendicular to any surface.

1.4) When the part consists of materials (weld zone is included) where the coefficient of linear expansion differs, it refers to the number of repetitions of temperature fluctuation that produces the relation, $(\alpha_1 - \alpha_2) \Delta T > 0.00034$. In this formula, α_1 and α_2 are average coefficient of linear expansion (1/°C). ΔT is the entire range of temperature fluctuation during operation (°C). This provision shall not apply to the clad steel specified in 6.1.7.

2) Conditions B The case when all the provisions of 2.1) to 2.6) are satisfied.

2.1) The case when the foreseeable (design) repetitive number of pressure cycles of entire range including start and stop does not exceed the value obtained as follows. Refer to the design fatigue curves specified in annex 8. Calculate S_a by multiplying three times the design stress strength, S_m , of material at an operating temperature.

- 2.2) The case when the foreseeable (design) range of pressure cycle during normal operation ⁽⁹⁾ does not exceed the value of $\frac{1}{3}$ (design pressure) $\times \left(\frac{S_a}{S_m} \right)$. Here, S_a is the allowable stress amplitude corresponding to the designated repetitive number of significant pressure fluctuation in the design fatigue curve of the said material. S_m is the design stress strength of the said material at an operating temperature.

If the designated repetitive number of significant pressure fluctuation exceeds 10^6 , then, S_a may be replaced by the value corresponding to $N = 10^6$.

The significant pressure fluctuation refers to the case where the range exceeds the value of $\frac{1}{3}$ (design pressure) $\times \left(\frac{S}{S_m} \right)$.

Here, S may be replaced by the value of S_a that corresponds to 10^6 cycles in the said design fatigue curve.

Note ⁽⁹⁾ A normal operation means a combination of all the service conditions, except start and stop, that are set to achieve the intended functions of the vessel.

- 2.3) The case when, during normal operation ⁽⁹⁾ and start and stop, the temperature difference between any two adjacent points ⁽⁸⁾ does not exceed $\frac{S_a}{2E\alpha}$. Here, S_a is the allowable stress amplitude corresponding to the designated repetitive number of start and stop in the said design fatigue curve. The value of α is an instantaneous coefficient of linear expansion in the two-point average temperature as specified in attached table 4.2. The value of E is longitudinal elastic coefficient at average temperature of the two points as specified in attached table 4.1.
- 2.4) The case when, during normal operation ⁽⁹⁾, the temperature fluctuation range between any two adjacent points ⁽⁸⁾ does not exceed $\frac{S_a}{2E\alpha}$. Here, S_a is the allowable stress amplitude corresponding to all the designated repetitive number of significant temperature difference fluctuation in the design fatigue curve of the said material.

The significant temperature difference fluctuation refers to the case where the range of temperature difference fluctuation exceeds the value of $\frac{S}{2E\alpha}$. Here, S may be replaced by the value of S_a that corresponds to 10^6 cycles in the said design fatigue curve.

- 2.5) The range ΔT of significant temperature fluctuation applied to components of different materials shall not exceed the lower value of ΔT that is calculated by the following formula for both materials.

$$\Delta T = \frac{S_a}{2E(\alpha_1 - \alpha_2)}$$

Here, S_a is the value of allowable stress amplitude calculated by the design fatigue curve of both materials, corresponding to the sum of designated repetitive number of significant temperature fluctuation. The values, α_1 and

α_2 , are instantaneous coefficients of linear expansion of both materials at the average temperature of the temperature fluctuation range. The value of E is the reference value of longitudinal elastic coefficient used for the said design fatigue curve.

The significant temperature fluctuation refers to the case where the range exceeds the lower value of $\frac{S}{2E(\alpha_1 - \alpha_2)}$ that is calculated for both materials. Here, S may be replaced by the value of S_a of allowable stress amplitude that corresponds to 10^6 cycles of both materials. However, this provision shall not apply to the clad steel specified to 6.1.7.

- 2.6) The case when the range of the stress produced by the mechanical load (excluding pressure and including reactive force of piping) does not exceed S_a . Here, the value of S_a is the allowable stress amplitude corresponding to all the designated numbers of significant load fluctuation in the said design fatigue curve. If all the designated numbers exceed 10^6 , then, it may be replaced by S_a corresponding to $N=10^6$.

In addition, the significant load fluctuation refers to the case where the entire range of stress strength at that load exceeds the value of S_a corresponding to 10^6 cycles of the said design fatigue curve.

- c) **Conditions to determine the necessity of fatigue analysis for the nozzle with reinforcement plate and the attachments of non-solid structure** Fatigue analysis is not required when the nozzle with reinforcement plate and the attachments of non-solid structure satisfy all the conditions of either conditions C in 1) or conditions D in 2). Conditions C shall apply only to the pressure vessels made of the materials shown in annex 8 figures 1 to 4. If neither conditions C nor conditions D are satisfied, then, fatigue analysis shall be performed according to annex 8.

Except the nozzle reinforced at the minor diameter end of conical head according to the provision of 2.4.2 c) 2) of annex 1, if a reinforcement plate is attached, then, the main body and nozzle of pressure vessel shall satisfy 2.10 of annex 2.

- 1) **Conditions C** The case when steel materials are specified in attached table 2.1; their normal minimum tensile strength is 550 N/mm² or less; and the total repetitive number of the following 1.1) to 1.4) is 400 or less.
 - 1.1) The estimated (design) repetitive number of pressure cycles of the entire range including start and stop.
 - 1.2) The estimated repetitive number of operating pressure cycles in which the range of pressure fluctuation exceeds 15 % of the design pressure (it is not necessary to consider the pressure cycle produced by fluctuation of open-air conditions).
 - 1.3) The effective repetitive number of times of metal temperature fluctuation between two adjacent points⁽⁸⁾ of pressure vessel including the nozzle. The repetitive number of times of metal temperature fluctuation is multiplied by

the factors mentioned in b) 1.3). The results shall be summed up. When the temperature difference between two adjacent points are calculated, heat conduction shall be considered only for the welded cross section or solid cross section, and need not be considered for contact surface that is not welded.

- 1.4) When the part consists of materials (weld zone is included) where the coefficient of linear expansion differs, it refers to the number of repetitions of temperature fluctuation that produces the relation, $(\alpha_1 - \alpha_2) \Delta T > 0.000\ 34$. In this formula, α_1 and α_2 are average coefficient of linear expansion ($1/^\circ\text{C}$). ΔT is the range of temperature fluctuation during operation ($^\circ\text{C}$). This provision shall not apply to the clad steel specified in 6.1.7.
- 2) **Conditions D** The case when the following values are applied to conditions B of b) 2) and all the conditions of 2.1) to 2.3) are satisfied
 - 2.1) In 2.1) of conditions B, the ferrous material in attached table 2.1 shall take 4 instead of 3.
 - 2.2) In 2.2) of conditions B, the ferrous material in attached table 2.1 shall take $\frac{1}{4}$ instead of $\frac{1}{3}$.
 - 2.3) In 2.3) to 2.5) of conditions B, the ferrous material in attached table 2.1 shall take 2.7 instead of 2 of a denominator.

6.5 Shell and head

6.5.1 Shell which receives an internal pressure The shell which receives an internal pressure shall be as follows. However, a non-circular shell is excluded (for non-circular shells, see 6.14).

- a) **Cylindrical shell** The thickness of a cylindrical shell shall be calculated by the formula in 2.2 of annex 1.
- b) **Spherical shell** The thickness of a spherical shell shall be calculated by the formula in 2.3 of annex 1.
- c) **Conical shell** The thickness of a conical shell shall be calculated by the formula in 2.4 of annex 1.

6.5.2 Head which receives an internal pressure The head which receives an internal pressure and is not supported by the stay shall be as follows.

- a) The shape of head shall be as specified in figure 6.1.

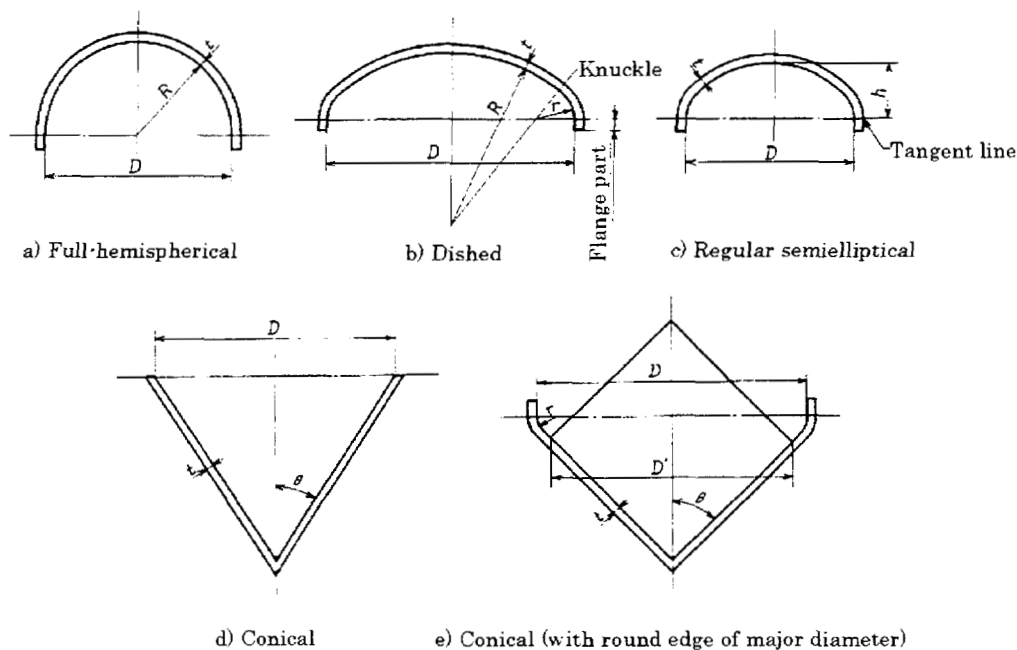


Figure 6.1 Shape of head

- b) The general matters about design of head shall be as follows.
- 1) The thickness of the flange part of head [see figures 6.1, a) to c) and e)] where a flange part is provided shall be calculated by the formula [see 6.5.1 a)] is used to calculate the thickness of the cylindrical shell of the same diameter.
 - 2) For the weld to the cylindrical shell whose thickness is different from that of head, refer to 7.2.1.
- c) **Full-hemispherical heads** [see figure 6.1 a)] The thickness of the full-hemispherical head which receives an internal pressure shall be calculated by the formula in 3.1 of annex 1.
- d) **Dished head** [see figure 6.1 b)] The thickness of the dished head that receives an internal pressure shall be calculated by the formula in 3.2 of annex 1.
- e) **Regular semielliptical head** [see figure 6.1 c)] The thickness of the regular semielliptical head that receives an internal pressure shall be calculated by the formula in 3.3 of annex 1.
- f) **Conical head** [see figure 6.1 d) or figure 6.1 e)] The thickness of the conical head which receives an internal pressure shall be calculated by the formula in 3.4 of annex 1.
- g) **Shape of a combination head** The head attached to a cylindrical shell may be made with butt welding of parts whose shapes are different. The thickness of each part shall satisfy provisions of b) to f).

In addition, the connection of parts with different shape shall have common tangent line at the connection point. The taper part of a joint shall be placed within the limit of part with thin thickness. (see figure 7.3).

- h) The thickness of the flat head which is attached with welding shall be calculated by the formula in 3.5 of annex 1.

6.5.3 Shell which receives an external pressure The shell which receives an external pressure shall be as follows.

- a) **Cylindrical shell** The thickness of the cylindrical shell which receives an external pressure shall be obtained with the procedure in 4.2 of annex 1.
- b) **Spherical shell** The thickness of the spherical shell which receives an external pressure shall be obtained with the procedure in 4.3 of annex 1.
- c) **Conical shell** The thickness of the conical shell which receives an external pressure shall be obtained with the procedure in 4.4 of annex 1. Moreover, the thickness of an eccentric conical shell be whichever thickness is larger, by calculating the maximum and the minimum of half-apex angle θ against a medial axis of conical shell.

6.5.4 Head which receives an external pressure The head which receives an external pressure shall be as follows.

- a) **Full-hemispherical head** The thickness of the full-hemispherical head that receives an external pressure shall be as specified in the provision of 4.5.1 of annex 1.
- b) **Regular semielliptical head** The thickness of the regular semielliptical head that receives an external pressure shall be as specified in the provision of 4.5.2 of annex 1.
- c) **Dished head** The thickness of the dished head that receives an external pressure shall be as specified in the provision of 4.5.3 of annex 1.
- d) **Conical head** The thickness of the conical head that receives an external pressure shall be as specified in the provision of 4.5.4 of annex 1.

6.5.5 Reinforcement of a shell which receives an external pressure The reinforcement of a shell which receives an external pressure shall be as follows.

- a) A stiffening ring of the cylindrical shell which receives an external pressure shall be as specified in the provision of 4.6.1 of annex 1.
- b) Reinforcement of the joint of a conical shell and a cylindrical shell shall be as specified in the provision of 4.6.2 of annex 1.
- c) The structure and attachment of a stiffening ring shall be as specified in the provision of 4.7 of annex 1.

6.6 Cover plate

- a) A bolted flat cover plate shall be as specified in the provision of 3 of annex 7.
- b) When a fitting type circular flat cover plate and flange type dished cover plate specified in clauses 4 and 5 of annex 8 of JIS B 8265 are used, annex 8 shall apply.

6.7 Bolted flange

6.7.1 The structure of a flange

6.7.1.1 Flanges other than the pipe flange for nozzle Flanges other than the pipe flange for nozzle used for the connection with the external piping, such as a body shell flange, shall be as follows.

- a) The stress of flange shall be calculated according to the calculation method specified in annex 3. It shall not exceed the allowance.
- b) Irrespective of the provision of a), a flange may be designed according to the stress analysis method and fatigue analysis method which are specified in annex 8. In this case, it is allowed to use only a provision of the bolt load of 4.1 of annex 3.
- c) The flange of a screwed type shall not be used.

6.7.1.2 Pipe flange for nozzle The pipe flange for nozzle used for the connection with the external piping shall be as follows.

- a) **Standard flange** For the pipe flange for nozzle used for the connection with the external piping, it is allowed to use the standard flange of JIS B 2220, JIS B 2238, JIS B 2240, JIS B 2241, ASME B16.5 or at least equivalent. However, the material of a standard flange shall be as specified in the provision of 5.2.1. Moreover, the joint and welding of a flange and a nozzle neck shall be as specified in the provision of clause 7 as a connector of classification C.
- b) When the standard flanges specified in a) are not used, the stress shall be calculated according to the calculation method specified in annex 3. It shall not exceed the allowance.

6.7.2 The material of a flange, and fabrication The material of a flange and fabrication shall be as specified in the provision of clause 5, and also they shall be as follows.

- a) The flange which is fabricated from steel material and is designed with annex 3 or annex 8 shall be normalized or fully annealed by heat treatment, when the thickness of a flange cross section exceeds 75 mm.

Remarks : The definition of terms, such as normalizing or full annealing shall be as specified in the number 2101 and number 2103 of JIS G 0201.

- b) The material to be welded shall have good weldability, and the welding procedure shall be as confirmed by JIS B 8285. Moreover, the ferrous material whose carbon content exceeds 0.35 % (molten analysis value) shall not be welded.
- c) The postweld heat treatment of the weld of a flange coupling shall be as specified in the provision of 10.1.
- d) Manufacture of a hub flange shall be as follows.
 - 1) The hub flange may be machined from either the steel bars of hot rolling, or the steel ingot of forging. The axis of the flange thus machined shall be parallel to the longitudinal axis of the original steel bars or steel ingot (this does not mean

that the axis is the same.).

- 2) Except the case specified in 1), the hub flange shall not be machined from the steel sheets or steel bars. However, if the material is fabricated to the ring form and the following conditions are met, then, machining is allowable.
 - 2.1) When a sheet is fabricated to the ring form, the surface of the original sheet shall be parallel to the axis of the flange thus fabricated (this does not mean that the surface of the original sheet appears on the flange thus fabricated.).
 - 2.2) The joint when a sheet is fabricated to a ring form shall be the butt weld joint. It shall pass the test that involves postweld heat treatment and weld and that is specified in this Standard. However, the thickness that determines the need for a postweld heat treatment shall be whichever is smaller of the following values.

$$t \text{ or } \frac{(A-B)}{2}$$

Where, t : Thickness of a flange (mm)

A : The outside diameter of a flange, or the diameter to the inside of a bolt hole when the slit-like bolt hole extends to the outside of a flange (mm)

B : The inside diameter of a flange (mm)

- 3) The rear surface of a flange and the outside surface of a hub shall pass the magnetic particle examination or liquid penetrant inspection by 11.3 c) or d).

6.8 Rapid closing-motion lid apparatus The rapid closing-motion lid apparatus used for a pressure vessel shall pass a stress analysis and fatigue analysis with annex 8.

6.9 Hole

6.9.1 General matters If a hole is provided at the pressure part of a pressure vessel and it receives only a pressure load, it shall be structured according to 6.9.2 to 6.9.7. However, special consideration shall be given to the piping load at the nozzle attachment of a pressure vessel, mass of attached instrument, etc.

6.9.2 The shape, dimension and reinforcement of a hole The shape, dimension and reinforcement of a hole shall be as specified in any method shown below.

- a) 2 of annex 2, Hole reinforcement [design method (1)]
- b) 3 of annex 2, Hole reinforcement [design method (2)]
- c) Stress analysis method and fatigue analysis method with annex 8

6.9.3 Thickness of a nozzle neck The thickness of the nozzle neck of a pressure vessel shall be as specified in following a) and b).

- a) Thickness of a nozzle neck shall be large than whichever is larger, either is the following 1) or 2), except a manhole and inspection hole.

- 1) The thickness calculated after selecting an applicable load from among the loads specified in 6.1.1, plus the corrosion allowance.
 - 2) The minimum thickness from among 2.1) to 2.4).
 - 2.1) For the vessel which receives only an internal pressure. The thickness calculated by the internal pressure of the shell or head to which a nozzle is attached, plus the corrosion allowance. However, it shall be the minimum limitation thickness or more specified in 6.1.4.
 - 2.2) For the vessel which receives only an external pressure. The thickness calculated by presuming that the shell or head to which a nozzle is attached receives "internal pressure" equivalent to the external pressure, plus the corrosion allowance. However, it shall be the minimum limitation thickness or more specified in 6.1.4.
 - 2.3) For the pressure vessel designed with both the internal pressure and the external pressure. Whichever is larger, either the thickness calculated in the above 2.1) or 2.2).
 - 2.4) The thickness specified in JIS G 3454. For the nominal pipe diameter 10B or less, the thickness of schedule 40 shall apply; for the nominal diameter 12B or more, the thickness of 9.5 mm minus negative tolerance of each pipe and plus the corrosion allowance shall apply.
- b) Thickness of the neck of a manhole and an inspection hole shall be that obtained by a) 1) or more.

6.9.4 Non-reinforced hole of formed head When a non-reinforced hole (for the hole where a pipe, etc. is welded, it is a welding edge.) is installed to a formed head, it shall not be placed at the round corner of head.

6.9.5 Tapped hole The hole to attach a pipe (except for a stay) or a screwed connector to a pressure vessel wall shall be as follows.

- a) **General tapped hole** The general matters about a tapped hole shall be as follows.
- 1) For the pressure vessel which contains the substances specified in the following 1.1) to 1.3), the connection by screwing exceeding nominal diameter 4B shall not be allowed.
 - 1.1) The liquid of flash-point of under 43 °C
 - 1.2) The combustible gas or lethal substances
 - 1.3) The flammable liquid whose temperature exceeds the boiling point in an atmospheric pressure
 - 2) For the pressure vessel whose design pressure is 1.0 MPa or more, the screw connection (except the welded connection after screwing) exceeding nominal diameter 3B shall not be installed. However, this provision does not apply to an inspection hole, a cover plate at the edge of shell or similar-purpose attachments, and a screwed cover plate used for openings that were forged together with the head.

- 3) A tapped hole shall be reinforced, as appropriate, by provision of annex 2.
- 4) In consideration of the curved surface of a vessel wall, the number of effective threads of screw and the required thickness of a sheet shall be the values or more shown in table 6.2 according to a pipe nominal diameter.

Table 6.2 Number of effective threads and required thickness of sheet

Pipe nominal diameter B	Number of effective threads	Required thickness of sheet mm
$\frac{1}{2}, \frac{3}{4}$	6	11
1, $1\frac{1}{4}$, $1\frac{1}{2}$	7	16
2	8	18

- 5) In order to protect the required thickness and the number of effective threads specified in table 6.2, if required, the cladding by welding, fitting sheet for weld attachment, or screw seat pipe joint shall be welded and used. The surface of the cladding by welding or attachment sheet shall be machined to make it flat. Moreover, if required, it may be used as a reinforcement.
- b) **When it is based on a taper pipe thread** When it is based on a taper pipe thread, it shall be as follows.
- 1) A screw shall be as specified in JIS B 0203.
 - 2) A taper pipe thread connector exceeding nominal diameter 2B shall not be used.
- c) **When it is based on a parallel thread** When it is based on a parallel thread, it shall be as follows.
- 1) A parallel thread shall be as specified in JIS B 0202 or a parallel thread which has the strength at least equivalent to a taper pipe thread.
 - 2) The joint by the parallel thread shall have collar or the surface machined by the similar method. The example is shown in figure 6.2.

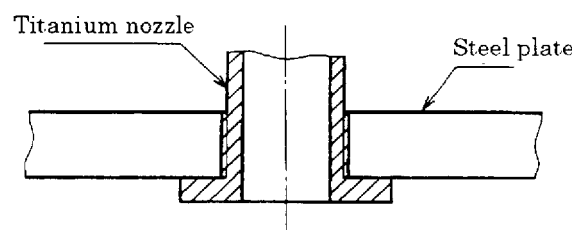


Figure 6.2 Example of attaching nozzle of different metals with parallel thread

- 3) The parallel thread connector exceeding nominal diameter 2B may be used when fatigue analysis is exempted by provision of 6.4.3. When a fatigue analysis is not exempted, a provision of annex 8 shall be used to perform a stress analysis and fatigue analysis.

6.9.6 Anchoring of the tubes by the expander It is not allowed to insert a tube, heat transfer tube, or forged joint (hereafter referred to as “a tubing”) into the hole of a pressure vessel wall, and to expand a tubing with an expander.

6.9.7 Anchoring with a stud When a stud is anchored directly to the shell or the head, or when a stud is anchored to the wear plate which is attached to the shell or the head, refer to the following.

a) When a stud is anchored directly to the shell or the head, refer to the following.

- 1) When a joint with a tap-end screw receives an outside load, it is required to prepare the tapped hole shown in 2). It is required to machine and smoothen the surface of the pressure vessel or welded overlay which will have a joint with a tap-end screw. It is not allowed to prepare the tapped hole within $\frac{1}{4}$ of the thickness from the inside surface of pressure vessel after corrosion. When the minimum required thickness is not implemented by these, it is allowed to implement this requirement by carrying out welding padding to an internal surface of vessel.
- 2) When preparing the tapped hole for studs, it is required to prepare a perfect thread part covering the overall length of a tapped hole. Moreover, the penetration depth of a stud shall be larger than any of 2.1) and 2.2). However, it is not necessary to make it $1.5d_s$ or more.

2.1) Root diameter d_s of a stud

$$2.2) \quad (0.75d_s) \times \frac{\text{Design stress strength at design temperature of stud material}}{\text{Design stress strength at design temperature of material where the tapped hole is prepared}}$$

b) In preparing a stud in a wear plate, refer to the following.

- 1) It is allowed to use the joint of a wear plate type with a stud hole as shown in attached figure 4 d), when an excessive mechanical load does not interact on the part like an inspection hole and the joint for instrumentation.
- 2) A wear plate installation part shall satisfy a provision of reinforcement of the hole of annex 2.
- 3) A tapped hole shall be as specified in a provision of a) 2).
- 4) Wear plate installation welding shall be as specified in attached figure 4 d).

6.9.8 Ligament effectiveness The ligament effectiveness used for the stress analysis of the ligament of a tube sheet shall be as specified in 5 of annex 8.

6.10 Tube sheet

6.10.1 Tube sheet of a multi-pipe tubular-type heat exchanger The tube sheet of a multi-pipe tubular-type heat exchanger shall be as follows.

a) Design of a tube sheet shall be as follows.

- 1) Calculation of a tube sheet shall be as specified in the stress-analysis method, fatigue analysis method, and other related analysis methods specified in annex 8. Moreover, as appropriate, a thermal-stress analysis shall also be performed.
 - 2) A holding-force test of a heat transfer tube and a tube sheet shall be as specified in 5.5 of JIS B 8274.
 - 3) Thickness of a tube sheet shall be larger than the calculated thickness; plus whichever is larger, either the corrosion allowance of a tube side, the depth of a partition groove, or the depth of a gasket groove; plus the corrosion allowance of a shell side.
- b) When the safety of differential-pressure design is assured and when it is approved by a user, it is allowed to design by a differential pressure.
- c) The weld of a tube sheet and a heat transfer tube shall be a type of weld of a tube sheet and a heat transfer tube specified in 5.4 of JIS B 8274.

6.10.2 Shell tube sheet not supported by heat transfer tube or a stay When a part of cylindrical shell or non-cylindrical shell becomes a tube sheet of shell tube sheet, and when a tube sheet is not supported by the heat transfer tube or the stay, the thickness of the tube sheet shall be as follows.

Remarks : The tube sheet which is not supported by the tube or the stay bolt means the tube sheet where more than 80 % of the pressure load on a tube sheet is not supported by a heat transfer tube or the stay bolt.

- a) By a provision of annex 8, a stress analysis and fatigue analysis shall be performed and a required thickness shall be calculated.
- b) Thickness of a tube sheet shall be larger than the thickness calculated by a); plus the corrosion allowance; plus the depth of a partition groove.

6.10.3 The tube sheet of a multi-pipe tubular-type heat exchanger and the tube sheet united with the cylindrical shell which are supported by the stay The tube sheet of a multi-pipe tubular-type heat exchanger and the tube sheet united with the cylindrical shell which are supported by the stay bolt shall be designed by performing a stress analysis and fatigue analysis with annex 8.

6.11 Flat head supported by stay bolts The design of flat head supported by stay bolts requires a stress analysis and fatigue analysis with annex 8.

6.12 Expansion joint

6.12.1 Necessity of an expansion joint A stationary-tube-sheet type heat exchanger and a pressure vessel of a jacket structure generate the temperature gradient or pressure differential between shell and heat transfer tube, or between shell and jacket. This causes tensile stress or compressive stress in a shell, heat transfer tube, or a jacket. If the stress exceeds a tolerance limit, it is required to prepare an expansion joint in the body of a pressure vessel or jacket.

About necessity of an expansion joint, it shall be as specified in the stress-analysis method, fatigue analysis method, and other related analysis methods specified in annex 8.

6.12.2 Design of an expansion joint Design of an expansion joint requires a stress analysis and fatigue analysis with annex 8.

6.13 Jacket The pressure chamber attached in the outside of a pressure vessel with welding is called jacket. The material, design, welded-joint design, machining, a postweld heat treatment, a test, and an inspection shall be as follows.

Remarks : For the range and type of jacket, refer to clauses 1 and 4 of JIS B 8279 respectively.

- a) In manufacturing a jacket, refer to the following.
 - 1) Design requires a stress analysis and fatigue analysis by 6.4.1. However, when it is exempted by 6.4.2 and 6.4.3, it is not necessary.
 - 2) A material, welded-joint design, machining, a post weld heat treatment, a test, and an inspection shall be as specified in a provision of this Standard.
- b) In manufacturing a jacket by JIS B 8265, it shall be as specified in JIS B 8279. However, the part which attaches the jacket to the pressure vessel of this Standard requires a stress analysis and fatigue analysis by 6.4.1.

6.14 Noncircular shell When a pressure vessel of this Standard whose cross section is rectangle, obround or ellipsoidal is manufactured, refer to the following.

- a) Design requires a stress analysis and fatigue analysis with annex 8.
- b) A material, welded-joint design, machining, a post weld heat treatment, a test, and an inspection shall be as specified in provisions of this Standard. However, the classification by the location of the weld joint of 7.1.1 shall be read as clause 8 of JIS B 8280.

6.15 Attachments and support structure Attachments and a support structure shall be as specified in annex 11.

6.16 Horizontal vessel of saddle support Design of horizontal vessel of saddle support requires a stress analysis and fatigue analysis with annex 8. However, when fatigue analysis is not required, it is allowed to perform a stress analysis by JIS B 8278.

7 Welded-joint design

7.1 General weld joint

7.1.1 Classification by the location of a weld joint The weld joint of the part which receives the pressure of a pressure vessel is categorized into the following A, B, C and D according to the location of a joint, and the typical joint is shows in figure 7.1.

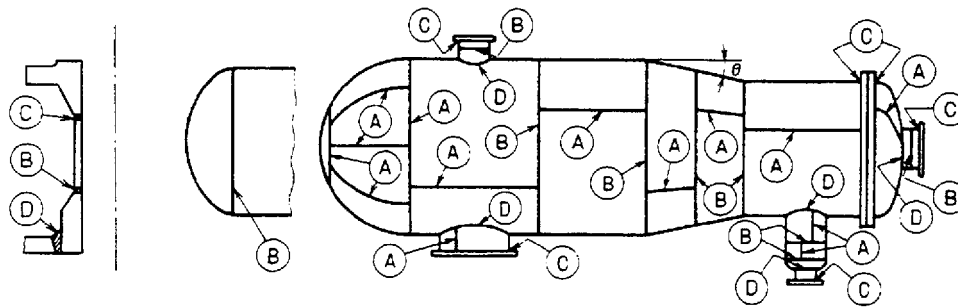


Figure 7.1 Classification by the location of a weld joint †

a) **Classification A** The following joint shall be the joint of classification A.

- 1) The longitudinal joint in the part which receives the pressure, such as a cylindrical shell, a conical shell, a nozzle, a connecting pressure chamber, etc.

Remarks : A connection pressure chamber is a pressure chamber which intersects the shell or a head of a pressure vessel and which subordinates to the vessel. For example, it is a sump, a dome, a manhole, etc.

- 2) All the weld joints in a spherical shell, a formed head, a flat head, or a cover plate.
- 3) The circumferential joint which attaches a hemispherical head to a cylindrical shell, a conical shell, a nozzle, or a connecting pressure chamber.

b) **Classification B** The following weld joint shall be the joint of classification B.

- 1) The circumferential joint in the part which receives the pressure of a cylindrical shell, a conical shell, a nozzle, a connecting pressure chamber, etc. It includes weld joint which joins a cylindrical shell or a nozzle neck at the large opening and the small opening of a conical shell.
- 2) The circumferential joint which attaches a formed head other than a full hemispherical head to a cylindrical shell, a conical shell, a nozzle, or a connecting pressure chamber.

Remarks : If a hub is provided for attaching a nozzle or a connecting pressure chamber to a shell, a head, etc., and it is the butt welding joint, then, it shall be classification B [see attached figure 2 e)].

c) **Classification C** The following weld joint shall be the joint of classification C.

The circumferential joint which attaches a flange, a stub end, a tube sheet, a flat head, or a jacket closing sheet to a cylindrical shell, a conical shell, a formed head, a nozzle, or a connecting pressure chamber.

d) **Classification D** The following weld joint shall be the joint of classification D.

- 1) The weld joint which attaches a nozzle or a connecting pressure chamber to a cylindrical shell, a spherical shell, a conical shell, a formed head, a flat head, or a cover plate.

2) The weld joint which attaches a nozzle to a connecting pressure chamber.

7.1.2 The type and its use range of a weld joint The type and its use range of a weld joint shall be as specified in table 7.1.

Table 7.1 Type and its use range of weld joint

The type of a weld joint		Use range
B-1 joint	The butt both-side-welding joint of full penetration, or the butt one-side-welding joint which is equivalent to this (see Remarks 1).	This may be used for all the joints from classification A to classification D (see Remarks 2).
B-2 joint	The butt one-side-welding joint using a backing, and leaving a backing. In this case, a backing shall be continuous thing, and the gap shall be butt welded.	1) This may be used only for the joint of classification B from which a backing cannot be removed (see Remarks 3). However, this shall not be used for 2). 2) This shall not be used for the weld joint with high tensile strength steel and for the pressure vessel aiming at handling lethal substances.
FP joint	The corner weld joint by groove weld of complete joint penetration welding, where two components are formed into L shape or T shape intersecting at the right angle. [see attached figure 1 b), attached figure 3, attached figure 6 a) to c), attached figure 7 a) 5), 6), and attached figure 7 b) 1)] 1) FP joint is a groove weld covering all thickness of at least one component in the components to join. It shall be welded to both components completely. 2) FP joint may be used together with FW joint [see attached figure 4 a) to c)].	1) This joint can be used for the joint of classification C and classification D. However, it cannot be used for 2), 3), and 4). 2) About the weld joint using the heat-treated high tensile strength steel, this joint can be used only for the joint of classification D whose nominal thickness of a shell is 50 mm or more. However, FW joint shall not be used together. 3) This joint may be used for the joint of classification D of pressure vessel to handle the lethal substance. 4) About the weld joint which requires an impact test and about the joint of the classification C of the pressure vessel which requires a pressure test with gas, FW joint shall not be used together. 5) This joint may be used for the weld joint which has a non-pressure part and a stiffening ring.
PP joint	The corner weld joint by groove weld of partial joint penetration welding, where two components are formed into L shape or T shape intersecting at the right angle. [see attached figures 5 a) to c)] 1) For a nozzle anchoring joint, the minimum penetration depth of partial penetration shall be 1.25 times the nominal thickness of a nozzle neck. 2) PP joint may be used together with FW joint [see attached figure 7 b) 2-2)].	1) This joint may be used for the joint of the classification C which has a nozzle flange. However, it shall not be used for 3). 2) Only when a manhole and an inspection nozzle used only for fabrication and inspection are involved; only when a thermometer protecting tube which does not receive the mechanical load from the outside is involved; and only when the thermal stress is smaller than that of the body of a pressure vessel, this joint may be used for the joint of classification D. However, it shall not be used for 3). 3) This joint shall not be used for the weld joint which uses the heat-treated high tensile strength steel; the weld joint which requires an impact test; a pressure vessel to handle the lethal substance; and the pressure vessel which requires a pressure test with gas. 4) This joint may be used for the weld joint which has a non-pressure part and a stiffening ring.
FW joint	The fillet-weld joint whose weld cross section is almost triangular, which joins two planes almost at the right angle, and whose throat is more than 70 % (a minimum of 6 mm) of the nominal thickness of the thinner component to be welded.	1) If the base material is classified as P-1 group numbers 1 and 2, the P-3 group numbers 1 and 2, P-8A, and P-8B, if it is used to manufacture a pressure vessel, and if a socket-weld type flange is attached to the vessel, then, this joint may be used for the joint of Classification C [see attached figure 7 b) 2-1)]. However, it shall not be used for 3). 2) If the base material is classified as P-1 group number 1 and 2, P-3 group numbers 1 and 2, P-8A, P-8B, P-21 to P-25 and P-27, P-31 to P-35, and P-41 to P-45, if it is used to manufacture a pressure vessel; and if the vessel is provided with an inner screw tube joint of nominal diameter 2B or less or with a stud-bolt hole joint which does not receive external load, then, this joint may be used for the joint of Classification D [see attached figure 6 d)] and attached figure 4 d)]. However, it shall not be used for 3). 3) This joint shall not be used for the weld joint which uses the heat-treated high tensile strength steel; the weld joint which requires an impact test; a pressure vessel to handle the lethal substance; and the pressure vessel which requires a pressure test with gas. 4) This joint may be used for the weld joint which has a non-pressure part and a stiffening ring.