

Australian Standard®

Pressure equipment—Manufacture

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PREFACE

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee ME/1 on Pressure Equipment.

This Standard is the result of a consensus among Australian and New Zealand representatives on the Joint Committee to produce this document as an Australian Standard. Consensus means general agreement by all parties. Consensus includes an attempt to remove all objections and implies much more than the concept of a simple majority, but not necessarily unanimity. It is consistent with this meaning that a member may be included in the Committee list and yet not be in full agreement with all clauses of this Standard.

This Standard is one of the ‘core’ documents which form part of the revised arrangement of the pressure equipment Standards; and is intended to unify and revise the manufacturing requirements for the pressure equipment Standards, AS 1210, *Pressure vessels*, AS 1228, *Pressure equipment—Boilers* and AS 4041, *Pressure piping*.

In this way misunderstanding, cost and delay in manufacture can be reduced and safety can be improved. It is intended to avoid unnecessary duplication and promote greater confidence in reciprocal acceptance of qualified procedures.

This Standard is based largely on AS 1210, with due allowance for practices or requirements of AS 1228 and AS 4041.

Requirements have been formulated with a view to maximum compatibility with recognized International Standards.

Statements referred in mandatory terms in notes to tables and figures are deemed to be requirements of this Standard.

The terms ‘normative’ and ‘informative’ have been used in this Standard to define the application of the appendix to which they apply. A ‘normative’ appendix is an integral part of a Standard, whereas an ‘informative’ appendix is only for information and guidance.

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STANDARDS AUSTRALIA

Australian Standard

Pressure equipment—Manufacture

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE This Standard sets out requirements for the manufacture of pressure equipment as specified in the pressure equipment Standards AS 1210, AS 1228 and AS 4041. Fabrication, heat treatment, forged construction, cast construction and testing are covered.

1.2 APPLICATION This Standard is intended for use by designers, manufacturers, fabricators, inspection bodies, inspectors and all persons concerned with the manufacture of pressure equipment.

This Standard applies to pressure equipment covered by AS/NZS 1200 and AS 3920.1.

The relevant requirements of AS/NZS 1200 apply to this Standard.

1.3 REFERENCED DOCUMENTS A list of the documents referred to in this Standard is given in Appendix A.

1.4 DEFINITIONS For the purposes of this Standard, the definitions below apply.

1.4.1 Construction—design, manufacture and supply. (See Figure 1.1).

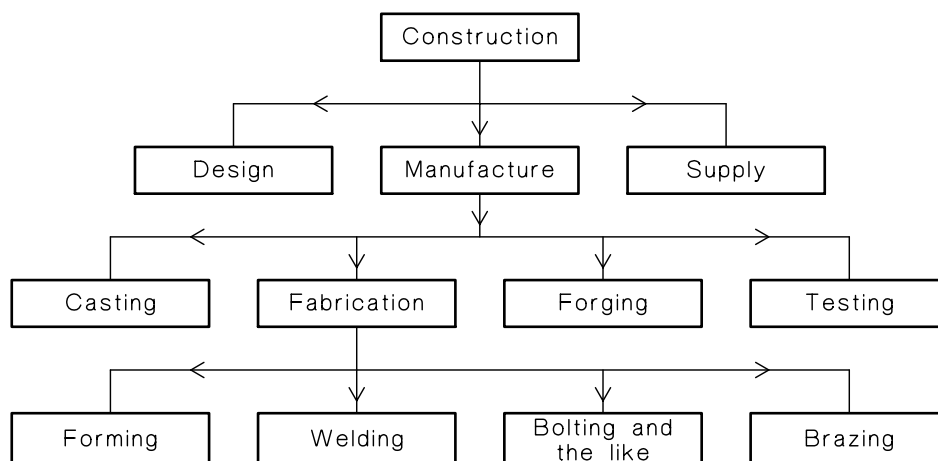


FIGURE 1.1 TERMS USED IN CONSTRUCTION

1.4.2 Designer—a person who designs pressure equipment or is responsible for the design.

1.4.3 Fabrication—the forming and joining of pressure equipment components which includes cutting, bending, rolling, pressing, swaging, upsetting, threading, welding, brazing, machining and any other operation on these components, but which is not part of installation.

NOTE: Fabrication may be carried out in the shop or on site.

1.4.4 Fabrication inspection body—a body corporate, firm or person, able to provide the inspection services of materials and construction of pressure equipment.

NOTE: In this Standard, 'fabrication inspection body' is referred to as the 'inspection body'. Where such a body is not appointed, the owner should refer to purchaser.

1.4.5 Inspector—a person carrying out fabrication inspection for the purpose of ensuring conformity with specified requirements.

1.4.6 Manufacturer—a body corporate, firm or person who manufactures pressure equipment.

NOTE: In this Standard, 'manufacturer' includes 'fabricator', 'constructor', 'assembler', 'installer' and 'erector', and is used to embrace all or some of these terms and is applicable to all locations, on or off site, where pressure equipment may be manufactured. It is recognized that different operations may be carried out by different organizations.

1.4.7 May—indicates that a statement is optional.

1.4.8 Parties concerned—the purchaser, designer, manufacturer, design verification body, fabrication inspection body, supplier, installer and owner as appropriate.

1.4.9 Pipe—a pressure-tight cylinder used to convey a fluid or to transmit a fluid pressure, ordinarily designated 'pipe' in the applicable material specification.

NOTE: For the purpose of this Standard, the term 'pipe' is synonymous with 'tube' except where otherwise noted.

1.4.10 Pressure equipment—boilers, pressure vessels, pressure piping and their components covered by AS/NZS 1200.

1.4.11 Shall—indicates that a statement is mandatory.

1.4.12 Should—indicates a recommendation.

1.4.13 Tube—See definition for 'Pipe' in this Clause (1.4).

SECTION 2 MATERIAL GROUPING

This Standard uses the material grouping system given in AS 3992 and applied throughout the pressure equipment Standards. Table 2.1 lists the material grouping for all metallic materials.

A list of typical ferrous material specifications, cross-referenced to the material group, is given in Appendix B. The design strength tables of AS 1210, AS 1228 and AS 4041 contain the material grouping for each specification listed.

TABLE 2.1
MATERIAL GROUPING

FERROUS MATERIALS (see Note 1)				
Material group	Material type	Typical nominal composition or Standard	ANSI/ASME BPV-IX classification	
			P number	Group number
CARBON STEEL				
A1	Carbon and carbon-manganese steel (low strength) (see Note 2)	AS 1548: 7-430, 7-460	1	1
A2	Carbon and carbon-manganese steel (medium strength) (see Note 3)	AS 1548: 5-490, 7-490	1	2
A3	Carbon and carbon-manganese steel (high yield strength)	API 5L: X52, X60, X65 and X70	—	—
		AS 1594: XF400 and XF500	—	—
LOW ALLOY STEEL				
B	Alloy steel (alloy < 3/4)	C-1/2Mo; 1/2Cr-1/2Mo; 1Mn-1/2Mo	3	1, 2, 3
C	Alloy steel (3/4 ≤ total alloy < 3)	1Cr-1/2Mo; 1/1/4Cr-1/2Mo; 3/4Cr-3/4Ni-Cu-Al	4	1, 2
D1	Alloy steel (vanadium type)	1/2Cr-1/2Mo-1/4V; Mn-Cr-Mo-V	—	—
D2	Alloy steel (3 ≤ total alloy < 10)	21/4Cr-1Mo; 5Cr-1/2Mo;	5A	1
		7Cr-1/2Mo 9Cr-1Mo	5B	1
E	31/2 nickel steel	31/2Ni	9B	1
F	9 nickel steel	9Ni	11A	1
G	Quenched and tempered low alloy steel	ASTM A517, AS 3597:700 PV	11B	1 to 8
HIGH ALLOY STEEL				
H	Martensitic chromium steel	13Cr (Type 410)	6	1, 2, 3, 4
		15Cr (Type 429)	—	—
		12Cr-1Mo-V(W)	—	—
J	Ferritic high chromium steel (11-13Cr)	12Cr-A1 (Type 405) 13Cr-Low C (Type 410S)	7	1
K	Austenitic chromium-nickel steel	18Cr-8Ni (Type 304) 18Cr-12Ni-2.5Mo (Type 316) 18Cr-10Ni-Ti (Type 321)	8	1

(continued)

TABLE 2.1 (continued)

FERROUS MATERIALS (see Note 1)				
Material group	Material type	Typical nominal composition or Standard	ANSI/ASME BPV-IX classification	
			P number	Group number
L	High chromium steel (>19Cr)	26Cr-0.5Ni-1Mo(S4426)	10E	1
M	Ferritic austenitic chromium-nickel steel	22Cr-5Ni-3Mo-N (S31803)	10H	1
NON-FERROUS MATERIALS				
Material group	Typical nominal composition or specification		ANSI/ASME BPV-IX P number	
ALUMINIUM AND ALUMINIUM ALLOYS				
Al 21	Al (99.0 min.) and Al-1.25Mn (1000 series and 3003)		21	
Al 22	Al-2.5Mg, Al-2.75Mg-0.75Mn, Al-1.2 Mn-1.0Mg (3004 and low strength 5000 series)		22	
Al 23	Al-Mg-Si-Cr alloys (selected 6000 series)		23	
Al 25	Al-4.5Mg-0.75Mn, Al-4Mg-0.5Mn (high strength 5000 series)		25	
COPPER AND COPPER ALLOYS				
Cu 31	Copper (99.0 min. Cu)		31	
Cu 32	Copper-zinc alloys		32	
Cu 33	Copper-silicon alloys		33	
Cu 34	Copper-nickel alloys		34	
Cu 35	Aluminium bronze alloys (>5 Al)		35	
NICKEL AND NICKEL ALLOYS				
Ni 41	Nickel and low carbon nickel		41	
Ni 42	Nickel-copper alloy (67Ni-3Cu only)		42	
Ni 43	Nickel-chromium-iron, nickel-chromium-molybdenum-iron		43	
Ni 44	Nickel-molybdenum, nickel-molybdenum-chromium-iron		44	
Ni 45	Nickel-chromium-molybdenum-copper, nickel-iron-chromium-molybdenum copper, nickel-iron-chromium		45	
Ni 46	Nickel-iron-chromium-silicon		46	
TITANIUM AND TITANIUM ALLOYS				
Ti 51	Unalloyed and alloyed titanium $R_m \leq 420$ MPa		51	
Ti 52	Unalloyed and alloyed titanium $R_m > 420$ MPa		52	

LEGEND:

 R_m = specified minimum tensile strength.

NOTES:

- See Appendix B for a list of common material specifications cross-referenced to material group.
- For these steels, an upper limit on tensile strength is also applicable as follows:
 - Where the steel specification includes a maximum tensile strength (or a hardness equivalent)—the lesser of 580 MPa and the value in the steel specification.
 - Where the steel specification does not limit the maximum tensile strength—580 MPa.
- For these steels, an upper limit on tensile strength is also applicable as follows:
 - Where the steel specification includes a maximum tensile strength (or a hardness equivalent)—the lesser of 620 MPa and the value in the steel specification.
 - Where the steel specification does not limit the maximum tensile strength—620 MPa.

SECTION 3 DRAWINGS AND PRODUCT QUALITY

3.1 CONSTRUCTION DRAWINGS Before commencing manufacture, drawing(s) containing the following information shall be supplied by the designer to the manufacturer unless otherwise agreed:

- (a) Pressure equipment Standard to which the item is to be constructed, the class of construction and hazard level of contents.
- (b) Specification for all items covered by the drawing(s).
- (c) Sufficient details to enable the preparation of welded joints.
- (d) Hydrostatic test pressure when required by the pressure equipment Standard.
- (e) When specified by the purchaser, details which may affect equipment integrity, e.g. surface treatment.

Drawings shall be fully dimensioned to the extent that construction can be completed to the stage of manufacture covered by the drawing.

Requirements for design verification are given in AS 3920.1.

3.2 COMPETENCE OF MANUFACTURER The manufacturer may be required by the inspection body or purchaser to demonstrate that the manufacturer's equipment and facilities are suitable for the type of work required, and that those engaged in the manufacture are capable of maintaining the required standard of workmanship. This demonstration should take place before work begins, and may take the form of acceptance of the overall quality system.

3.3 MANUFACTURE AND WORKMANSHIP The manufacturer of the pressure equipment shall—

- (a) be responsible for the quality of work;
- (b) conduct, or shall have conducted by a representative, all relevant examinations and tests specified in this Standard, the drawing(s), and the pressure equipment Standard; and
- (c) ensure that the examination, inspection and qualification requirements covering the processes listed in the pressure equipment Standard are undertaken at the required stage of manufacture.

3.4 QUALITY ASSURANCE Requirements for the assurance of product quality for pressure equipment manufacture are given in AS 3920.1.

3.5 INDEPENDENT INSPECTION Requirements for independent inspection are given in AS 3920.1.

3.6 REPORTS After each item of pressure equipment has been completed and tested, the manufacturer shall complete a report certifying that each item of pressure equipment has been designed, constructed and tested in compliance with the requirements of the applicable Standard.

This report, together with material test certificates, results of production weld test, heat treatment report and non-destructive examination reports, shall be furnished to the purchaser, and others, where specified on the order.

For pressure vessels constructed to AS 1210 the report shall be the manufacturer's data report as given in Appendix C.

For boilers constructed to AS 1228, the report shall be the manufacturer's data report as given in Appendix A of AS 1228.

For piping constructed to AS 4041, the report shall be the manufacturer's data report as given in Clause 1.11 of AS 4041.

SECTION 4 MATERIAL IDENTIFICATION

4.1 GENERAL The manufacturer of the pressure equipment shall be able to demonstrate that the material used in manufacture is in accordance with the appropriate material specification as specified on the manufacturing drawing(s). The requirements for material identification vary according to:

- (a) Class of construction of the pressure equipment.
- (b) Use of standard or non-standard components in manufacture and the various requirements covering these as specified in Clause 4.2.

Traceability requirements are given in AS 3920.1.

4.2 TYPES OF IDENTIFICATION OF MATERIALS Identification of incoming materials consist of the following types:

- (a) *Type A identification*—covers materials and components identified by surface marking only in accordance with a national Standard and which are covered by a test certificate.
- (b) *Type B identification*—covers pressure components which are produced in quantity in accordance with acceptable component Standards (e.g. flanges, nozzles, pipe fittings, and valves) which do not require full identification and test certificates where they are wholly formed by casting, forging, rolling or die forming. However, they shall be marked with the name or mark of the component manufacturer and such other markings required by the component specification to identify the grade of material. Such markings shall be considered as the component manufacturer's certification that the components comply with the material specifications and Standards indicated, and are suitable for service at the rating indicated.
- (c) *Type C identification*—covers materials and components identified by surface marking in accordance with a national Standard. Test certificates are not required.

The type of material identification required for various pressure equipment components is shown in Table 4.1. Test certificates when required by Items (a) to (c) shall be retained by the manufacturer and shall be made available for inspection by inspector or purchaser.

4.3 MATERIAL NOT FULLY IDENTIFIED Material which is not fully identified with a national Standard may be accepted provided that each piece is shown to the satisfaction of the inspector (and to the purchaser when specified) to have chemical composition, mechanical properties and heat treatment requirements complying with a relevant national Standard and, additionally meet the requirements of non-destructive examination when applicable.

4.4 IDENTIFICATION AND MARKING

4.4.1 Identification The manufacturer shall be able to demonstrate the identity of material in accordance with Clauses 4.1 and 4.2.

TABLE 4.1
IDENTIFICATION OF PRESSURE COMPONENTS

Pressure component (Note 1)	Type of identification (see Clause 4.2)				
	Construction Standard/class of construction				
	AS 1210		AS 1228	AS 4041	
	CL1H, 2H, 1&2	CL3	CL1 & 2	CL1 & 2	CL3
Pressure vessel strakes	A	C	A	—	—
Pressure vessel heads	A	B or C	A	—	—
Nozzle necks	A	C	A	A	C
Standard flanges (Note 2)	B	B	B	B	B
Non-standard flanges (Note 3)	A	A	A	A	A
Non-pressure attachments (Note 2)	C	C	C	C	C
Pressure piping	A	C	A	A	C
Standard flat covers (Note 2)	B	C	B	B	C
Non-standard flat covers (Note 4)	A	A	A	A	A
Pipe fittings and valves (Note 2)	B	B	B	B	B
Boiler tubing (Note 5)	—	—	C	—	—
Heat exchanger tubing	C	C	—	—	—
Instrument piping	C	C	C	C	C
Safety relief devices	B	B	B	B	B

NOTES:

- 1 Pressure vessels are inclusive of drums and headers as defined in AS 1228.
- 2 Non-pressure and pressure attachments require impact test certificates when specified in an application Standard for low temperature service.
- 3 Flanges designed in accordance with AS 1210.
- 4 Covers designed in accordance with AS 1210.
- 5 Boiler tubing covers furnace wall, economizer, attemperator, superheater and reheater tubing.

4.4.2 Transfer of marks Where original markings are not retained on parts cut from certified material and Type A identification is required, markings necessary to prove the identity of the materials shall be transferred. Coded markings may be used provided that these can be proven to adequately identify the material with the original manufacturer's certificate. Re-marking shall be witnessed by the inspector unless otherwise agreed, in which case the inspector shall be satisfied that the re-marking has been carried out in accordance with agreed procedures.

Where agreed by the manufacturer and inspection body, an alternative method is to transfer all relevant material identification to a reproducible drawing with the provision for the manufacturer and the inspector to sign, thereby verifying the original identification.

4.4.3 Method of marking Materials shall be marked by any means which do not impair the suitability of the material for its intended service.

Carbon or alloy steel components which will be heated above 425°C during fabrication or service shall not be contaminated by non-ferrous metals or sulfur compounds. Paint, labels, or tools used for identification or fabrication in such processes shall not contain lead, copper, zinc or tin in excess of 250 parts per million. Iron oxide, titanium or aluminium based paints are satisfactory for material marking.

With high alloy steels, group F and group G steels and, except where the stamping is located in areas of low stress, carbon, carbon-manganese and low alloy steels for service below -20°C , and with non-ferrous metals, die stamping may be harmful for some service conditions. To guard against the formation of incipient or service cracks in steel plates less than 6 mm thickness and in non-ferrous plates less than 12 mm thickness, the material manufacturer's marking shall be transferred in any suitable manner other than by deep die stamping. For carbon and alloy steels intended for service at temperatures below 0°C , low-stress stamping using letters and similar formed by a series of small hemispherical dots is recommended for use on the surface of the plate.

Die stamping shall not be used for component parts of group F and group G steels less than 12 mm thick, except that the low stress type stamping on the rim of a flange is permitted.

Centre-punch markings should not be used for carbon, carbon-manganese and low alloy steels where these marks will remain in a finished vessel which is not postweld heat treated and is to be used at a temperature colder than the material design minimum temperature plus 15°C .

4.5 DEFECTS IN MATERIALS Material shall be visually examined for surface defects. Material found to have defects in excess of that permitted in the material specification or which has been damaged so as to render it unsuitable for its intended purpose, shall not be used in the manufacture of a component. Acceptance of any repair method and the extent of repair of minor defects shall be obtained from the inspection body and purchaser unless the method of repair is specified in the material Standard.

SECTION 5 MATERIAL CUTTING

5.1 GENERAL Material may be cut to shape and size by any suitable method including machining, shearing, chipping, grinding, thermal cutting and abrasive jet, provided that the material is not impaired for its intended service.

NOTE: Thermal cutting includes flame, plasma, laser and electric arc methods of cutting.

5.2 THERMAL CUTTING Thermal cutting should adopt preheating in accordance with Table 5.1.

After flame or arc cutting, all slag, burnt metal, scale or other defective material shall be removed by an appropriate method prior to further fabrication or use except where varied by this Clause (5.2). Surface discolouration which may remain on flame cut surfaces of groups A1, A2, A3 and B steels shall not be considered to be detrimental.

Parent metal shall be removed where required by Table 5.1. This requirement may be varied in accordance with a procedure for thermal cutting which has been proven to have no detrimental effect on subsequent processing or service.

For group A1, A2, A3 and B steels used in the following applications, a minimum of 1 mm shall be removed from the cut surfaces which remain unfused in the final product:

- (a) Parts to be used at a temperature which requires impact testing of the material to attain a suitable material design minimum temperature.
- (b) Pressure parts to be used in the construction of a transportable vessel, and subject to internal inspection.

For groups C to M and non-ferrous materials, a minimum of material, in accordance with Table 5.1 shall be removed from cut surfaces which remain unfused in construction except that these conditions may be varied in accordance with a procedure for thermal cutting which has been proven to have no detrimental effect.

Thermally cut surfaces of non-pressure parts which are welded directly to pressure parts shall be treated in the manner required for cut surfaces of pressure parts.

Where grinding is applied care shall be taken to avoid excessive heating and grinding cracks, particularly in group C to J steels inclusive and any materials to be subsequently bent or formed to shape.

TABLE 5.1
THERMAL CUTTING

1	2	3	4	5
Material group (See Section 2)	Material type	Thickness mm	Recommended minimum preheat temperature (see Note 1) °C	Minimum material to be removed from each thermally cut face after cutting mm
CARBON, CARBON-MANGANESE AND LOW ALLOY FERRITIC STEEL				
A1 & A2	Carbon and carbon-manganese steel (low and medium strength) CE≤0.45 (see Note 2)	≤25 >25	0 10	0 (Note 3) 0 (Note 3)
A1 & A2	Carbon and carbon-manganese steel (low and medium strength) CE>0.45 (see Note 2)	≤25 >25	0 20	0 (Note 3) 0 (Note 3)
A3	Carbon and carbon-manganese (high yield strength steel)	≤32	0	0 (Note 3)
B	C-Mo, 1/2Cr-1/2Mo, 1Mn-1/2Mo	≤16 >16	10 75	0 (Note 3) 0 (Note 3)
C	1Cr-1/2Mo, 1 1/4Cr-1/2Mo	≤12 >12	10 100	1 1
	3/4Cr-1/2Ni-Cu, 3/4Cr-3/4Ni-Cu-A1	≤12 >12	10 100	1 1
D1	1/2Cr-1/2Mo-1/4V, 1Cr-1Mo-1/3V	All	150	1.5
D2	2 1/4Cr-1Mo, 5Cr-1/2Mo 7Cr-1/2Mo, 9Cr-1Mo	All	150	1.5
E	3 1/2Ni	All	200	1.5
F	9Ni	All	10	1
G	Quenched and tempered low alloy steel	All	25	1
HIGH ALLOY STEEL				
H	12Cr-Mo-V(W)	All	250	1.5
	13Cr	All	200	1
	15Cr	All	200	1
J	12Cr-1A1	All	0	1
K	18Cr-8Ni, 18Cr-10Ni-Ti 18Cr-10Ni-2Mo	All	0	1
L	27Cr	All	200	1
M	22Cr-5Ni-3Mo-N (S31803)	≤25	0	1
		>25	10	1
NON-FERROUS MATERIAL				
Al 21-25	Aluminium, aluminium alloys	} <25 ≥25	0 10	1 1
Cu 31-35	Copper, copper alloys			
Ni 41-46	Nickel, nickel alloys			
Ti 51 & 52	Titanium, titanium alloys			

NOTES TO TABLE 5.1:

- 1 The preheat temperature is the temperature approximately 100 mm from and ahead of the cutting torch at the time of cutting.
- 2 Carbon equivalent (%) = $C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15}$
Where heat analysis of all of the above elements is not known the value of $C + \frac{Mn}{6} \leq 0.42\%$ applies instead of the 0.45% given.
- 3 See Clause 5.2 for additional requirements for equipment operating at low temperature service and for transportable vessels.

5.3 MECHANICAL CUTTING AND EDGE PREPARATION Mechanical cutting using machine tool techniques may be used without restriction for cutting or edge preparation.

Cold shearing, e.g. by a guillotining process, may be used within the thickness limits of Table 5.2.

Sheared edges of pressure parts which are required by Table 5.2 to be treated, or which will not be fused by welding, shall be machined, ground or chipped back for a distance of not less than 1.5 mm to obtain undamaged metal.

The sheared edge of non-pressure parts welded to pressure parts shall be treated in the same manner as for pressure parts where the non-pressure part—

- (a) is to be used at a temperature which requires impact testing of the material to achieve a suitable material design minimum temperature; or
- (b) is attached to a pressure component on a transportable vessel.

5.4 EDGE EXAMINATION All edges after cutting and before carrying out any further work upon them shall be visually examined to detect laminations, cracks or gouges which may be present. When material is thermally cut visual examination of the edge should be made immediately after cutting. However, where delayed cracking may occur in groups F and G steels, edges shall be inspected at a more appropriate time, usually 48 h after cutting.

Thermally cut edges of quenched and tempered alloy steels which are not fully fused by welding shall be examined by magnetic particle or penetrant flaw detection methods (see AS 4037). Unacceptable imperfections revealed by this examination shall be repaired prior to further fabrication.

5.5 EDGE FINISH Cut edges not subsequently fused by welding shall be reasonably smooth and free from cracks, laminations and severe gouges, grooves or notches normal to the plate surface.

For piping Classes 1 and 2 such edges shall have a surface roughness of not greater than Class 3 as defined by WTIA Technical Note 5.

For pressure vessels which are Class 1, Class 1H or constructed of groups D to J steels and boilers, the surface roughness of cut edges shall be not greater than Class 2 as defined by WTIA Technical Note 5.

Edges which are to be incorporated into the weld shall be free from notches, sudden changes of shape, or imperfections which could be the cause of weld imperfections.

TABLE 5.2
SHEARING OF PLATES

Material group (see Section 2)	Material type and service	Maximum thickness of cold sheared material mm	Treatment of edges of pressure parts after shearing (see Note)
A1, A2, A3 B C D1, D2 E F	Carbon, carbon-manganese, and low alloy steels (for use at temperatures not requiring impact testing to achieve the required material design minimum temperature).	6	Not required
		>6 ≤25	Required (see Clause 5.3)
A1, A2 B C D1, D2 E F	Carbon, carbon-manganese, and low alloy steels (for use at temperatures requiring impact testing to achieve the required material design minimum temperature).	25	Required (see Clause 5.3)
G	Quenched and tempered low alloy steels	12	Required (see Clause 5.3)
H J K L M	High alloy steels	6	Not required
		>6 ≤25	Required (see Clause 5.3)
Al 21-25 Cu 31-35 Ni 41-46 Ti 51 and 52	Non-ferrous metals	10	Not required
		>10 ≤25	Required (see Clause 5.3)

NOTE: This treatment is not required when cut edges are to be subsequently welded.

SECTION 6 FORMING OF PRESSURE EQUIPMENT COMPONENTS

6.1 GENERAL Pressure equipment and components may be formed by any method which will produce finished components which are free from cracks or other defects, and have the required material properties, dimensions and tolerances in Section 7.

Typical methods of hot or cold forming include rolling, pressing, bending, swaging, upsetting and expanding.

Components may be formed by hot or cold forming methods provided that all necessary requirements specified in this Section are subsequently satisfied. In this Standard hot forming of steels is a process performed at a range of temperatures shown in Table 6.1 and the lower forming temperature is above the lower critical temperature of the material minus 50°C. Cold forming is forming at a lower temperature than hot forming.

Forming of pressure parts by machine is the preferred method of manufacture. Forming equipment and the material being formed shall be in a condition which will prevent detrimental scoring or contamination of the material.

The following general conditions apply in the forming of respective components of pressure equipment:

- (a) *Pressure vessel strakes or pipe cylinders* If the plates are to be rolled, the adjoining edges of longitudinal joints of cylindrical parts shall first be shaped to the proper curvature by preliminary rolling or bending in order to avoid flat areas along the completed joints.
- (b) *Dished ends* Where practicable, ends shall be made from one piece of plate and dishing and flanging carried out by machine. It is preferable that the flanging be done in one operation, but progressive machine forming may be used provided that—
 - (i) the plate is worked at a suitable temperature and is heated to an adequate distance beyond the portion under immediate treatment; or
 - (ii) the plate is cold formed in several stages, each of which is within the plastic strain limit shown in Clauses 6.3.1 to 6.3.4 as applicable, and is followed by a suitable intermediate heat treatment after each stage.

Straight flanges of dished ends shall be cylindrical and free from local irregularities.

- (c) *Pipe bending* Bends made from pipe containing a longitudinal weld, exclusive of tubing manufactured by the ERW process, shall be manufactured with the weld near the neutral axis of the bend. Where a bend is made in a pipe containing a circumferential weld, the weld shall not lie within the bend after forming unless the joint is subjected to non-destructive examination using ultrasonic or radiographic methods after forming. Bends shall be cleaned of filling material and injurious scale by pickling, blasting or other appropriate methods.

The surface of the bend shall be such as to permit an effective visual examination.

Bends made from pipe shall be free of cracks and unacceptable bulges, kinks, thinning and other irregularities.

An irregularity shall be considered a defect for continuous bends where—

- (i) it does not join smoothly with the adjoining surfaces; or
- (ii) its height is greater than 25% of the nominal thickness and the width of its base is less than eight times its height.

Areas which are ground to remove defects shall be examined by surface flaw detection methods appropriate to the material to ensure complete removal of the defect. (See also Clause 6.6).

6.2 HOT FORMING OF PRESSURE EQUIPMENT COMPONENTS

6.2.1 Ferritic steels—Material groups A to G Pressure equipment components may be hot formed by the methods nominated in Clause 6.1. The preferred temperature range for hot forming for various material groups is given in Table 6.1.

After forming, ferritic steel components shall be heat treated in accordance with the requirements of Table 6.1. Such heat treatment should comply with the requirements of Table 6.2 or the material supplier's recommendations. Pressure components may be hot formed outside of the preferred hot forming temperature range of Table 6.1 provided that such components are heat treated after forming in accordance with the requirements of Table 6.2. Tempering after normalising for material groups C, D1, D2 and E steels may be carried out in conjunction with postweld heat treatment (stress relief see Table 14.1) of welded joints provided that when such temperatures exceed the material tempering temperature, material and weld procedure tests are carried out to ensure that the material properties are not adversely affected and comply with the limits specified in the material Standards.

Pressure equipment components, formed from F and G group steels at a temperature equal to or higher than the original tempering temperature shall be heat treated as specified in Tables 6.1 and 6.2. Tests shall be carried out in accordance with Clause 14.18 to prove that material has the required properties.

The effect of loss of properties in pressure components that have been hot formed may be demonstrated by the heat treatment of tensile specimens simulating the hot forming and any subsequent heat treatment. The chosen wall thickness for components shall take any loss of properties into account using either the yield or tensile strength depending upon which property was used in the design stress for the component.

6.2.2 High alloy steels—Groups H to M steels Forming procedures for plate and pipe components, particularly those involving hot working, can markedly affect the properties of high alloy steels. The purchaser, manufacturer and material supplier shall give full consideration to the intended fabrication methods and service conditions in the selection of the particular material to be used. Such consideration may include tests made on samples which have been given the same fabrication processes including heat treatment, to ensure that the material is suitable for the service condition.

The following requirements shall apply:

- (a) Austenitic chromium-nickel (group K steel) which is to be hot worked shall be heated in a neutral or slightly oxidizing atmosphere. The heating shall be in an oil, gas or electric furnace, and the steel shall not come into contact with flame. Sulfur or sulfur containing materials which could give sulfur embrittlement shall be avoided. However, subject to agreement between the manufacturer and purchaser local heating which may be by electric means or by oil or gas flame may be used. In this case the purchaser may specify on the order, tests to check for carbon contamination.
- (b) Austenitic chromium-nickel (group K steel) which is to be hot worked shall be heated uniformly to a temperature which shall not exceed the maximum temperature nominated in Table 6.1 and under no circumstances shall deformation be carried out after the temperature of the material has fallen below 900°C. After hot forming the steel shall be rapidly cooled, or preferably solution annealed in accordance with Table 6.3.
- (c) Ferritic-austenitic components (group M steel) shall be hot formed within the temperature limits of Table 6.1 and shall be solution annealed after forming in accordance with the requirements of Table 6.3.
- (d) Austenitic chromium-nickel (group K steel) plates less than 6 mm thick may be locally heated to temperatures not over 800°C to facilitate local forming of knuckle radii and branch or manhole collars, subject to agreement between the purchaser and

the manufacturer. Areas so formed shall be visually examined for cracks after any scale has been removed.

- (e) Components of material groups H, J and L, hot formed within the temperature range of the Table 6.1 shall be normalized and tempered as required by Table 6.2 prior to any subsequent fabrication.

6.2.3 Non-ferrous metals Forming procedures including any heat treatment shall be carried out in accordance with the material supplier's recommendations unless the procedure is qualified by adequate tests to demonstrate that the end product is suitable for the intended service.

Hot forming should be carried out at temperatures given in Table 6.4.

6.2.4 Plates or pipes welded prior to hot forming When pressure equipment components are welded together prior to hot forming—

- (a) the welds should be dressed smooth prior to further forming;
- (b) the welding procedure applicable to such joints which are heated above the lower critical temperature, shall be subjected to the same heat treatment cycle as the relevant component; and
- (c) the manufacturer shall ensure that resultant weld metal properties are suitable for the intended service, in particular, for materials operating at elevated temperatures.

TABLE 6.1
HOT FORMING OF PRESSURE EQUIPMENT
COMPONENTS

Material group (See section 2)	Material type	Recommended Forming temperature range, °C	Recommended heat treatment after hot forming
A1 & A2	Carbon and carbon-manganese steel (low and medium strength)	850–950	None (Notes 1 and 2)
		950–1050	Normalize (Note 1)
A3	Carbon and carbon-manganese steel (high yield strength)	—	Note 1
B	Alloy steel (alloy < 3/4)	900–1100	None (Note 2)
C	Alloy steel (3/4 ≤ total alloy < 3)	900–1100	As per Material Test Certificate (Note 3)
D1	Alloy steel (Vanadium type)	950–1100	Normalize and temper (Notes 3 & 4)
D2	Alloy steel (3 ≤ total alloy < 10)	900–1100	As per Material Test Certificate (Note 3)
E	3 1/2 nickel steel	950–1000	Normalize and temper (Notes 3 & 4)
F	9 nickel steel	900–1000	Normalize and temper (Notes 3 & 4)
G	Quenched and tempered low alloy steel	900–1000	Quench and temper (Note 4)
H	Martensitic chromium steel	1020–1070	Normalize and temper (Notes 3 & 4)
J	Ferritic, high chromium steel	Use material supplier's recommendations	
K	Austenitic chromium nickel steel	925–1150	Solution anneal
L	High chromium steel	Use material supplier's recommendations	
M	Ferritic-austenitic chromium nickel steel	950–1100	Solution anneal

NOTES:

- 1 Material which has used thermo-mechanical controlled rolling procedures in manufacture requires appropriate procedural testing to prove that required mechanical properties have been retained and that the overall condition of the steel is not adversely affected. This testing will apply to some grades of AS 1548, AS 1594 and AS 3678 materials.
- 2 When material requires impact testing for low temperature service or has been supplied in the normalized condition, all hot formed pressure parts shall be normalized after cooling to room temperature.
- 3 The material should be heat treated to restore the heat treatment condition prior to hot forming, i.e. annealed or normalized and tempered as noted on material certificate see Table 6.2.
- 4 For tempering times and temperatures see Clause 6.2.1 or 6.2.2.

TABLE 6.2
NORMALIZING, QUENCHING AND TEMPERING OF
GROUPS A TO L STEELS

Material group (See Section 2)	Material type	Typical nominal composition or grade	Soaking temperature for normalizing (N) or quenching (Q) (Note 1) °C		Recommended time at temperature (Note 2) hours/25 mm thickness
A1	Carbon and carbon manganese steel (low strength) C ≤ 0.26%	AS 1548: 7-460 ASTM A 106A	(N)	870–930 Note 3	1/2 (1/4 h min.)
A1	Carbon and carbon manganese steel (low strength) C > 0.26% ≤ 0.30%	ASTM A 106B A106C	(N)	850–880	1/2 (1/4 h min.)
A2	Carbon and carbon- manganese steel (medium strength) C ≤ 0.26%	AS 1548: 7-490, 5-490	(N)	870–930 Note 3	1/2 (1/4 h min.)
A2	Carbon and carbon manganese steel (medium strength) C > 0.26 ≤ 0.35%	ASTM A 106-C	(N)	850–880	1/2 (1/4 h min.)
A3	Carbon and carbon manganese steel (high yield strength)	API 5L: X 52	See material supplier's recommendations		
B	Alloy steel (alloy <3/4)	C-1/2Mo 1/2Cr-1/2Mo	(N)	900–960 (Note 3)	1/2 (1/2 h min.)
C	Alloy steel (3/4 < total alloy < 3)	1Cr-1/2Mo 1 1/4Cr-1/2Mo	(N)	950–960 (Note 4)	1/2 (1/2 h min.)
D1	Alloy steel (vanadium type)	1/2Cr-1/2Mo-1/4V	(N)	950–980 (Note 4)	1/2 (1/2 h min.)
D2	Alloy steel (3 < total alloy < 10)	2 1/4Cr-1Mo 5Cr-1/2Mo 7Cr-1/2Mo } 9Cr-1Mo }	(N) (N) (N)	900–960 930–960 900–1000 (Note 4)	1/2 (1/2 h min.) 1 (1 h min.) 1 (1 h min.)
E	3 1/2Ni steel	3 1/2Ni	(N)	880–910 (Note 4)	1 (1 h min.)
F (Note 5)	9Ni steel	9Ni	(N)	890–930 (Notes 6,7,8)	Material supplier's recommend- ation
			(N)	780–820 (Notes 6,8,9)	
G (Note 5)	Quenched and tempered low alloy steel	ASTM A 517 (A, B, D, E, F, J, P) AS 3597-700PV	(Q)	900–940 (Notes 7, 10)	Material supplier's recommend- ation

(continued)

TABLE 6.2 (continued)

Material group (See Section 2)	Material type	Typical nominal composition or grade	Soaking temperature for normalizing (N) or quenching (Q) (Note 1) °C		Recommended time at temperature (Note 2) hours/25 mm thickness
			(N) (N)	1020–1070 750–800 (Note 4)	1 (1 h min.) 1 (1 h min.)
H	High alloy martensitic steel	12Cr-1Mo-V(W) 13Cr, 15Cr	(N) (N)	1020–1070 750–800 (Note 4)	1 (1 h min.) 1 (1 h min.)
J	High alloy ferritic steel	12Cr-1A1	(N)	750–800 (Note 4)	1 (1 h min.)
L	27Cr steel	27Cr	(N)	800–900 (Note 4)	1 (1 h min.)

NOTES:

- 1 For subsequent postweld heat treatment, see Table 14.1.
- 2 For thickness less than 25 mm, the minimum recommended holding time is calculated by proportioning holding time per 25 mm, however in no case shall this time be less than that shown in brackets.
- 3 This treatment is not required when material is formed within the temperature range listed in this Table and the product is not used in low temperature service requiring impact testing of material.
- 4 For post-forming tempering requirements see Clauses 6.2.1 and 6.2.2.
- 5 During normalizing and quenching precautions shall be taken to prevent excessive distortion.
- 6 Tempering is required at 565°C to 610°C.
- 7 The maximum cooling rate specified in Clause 14.7(f) need not apply.
- 8 The two temperature ranges are those required for double normalizing.
- 9 If postweld heat treatment is to be used subsequently, the cooling rate is to be not less than 170°C/h down to 300°C.
- 10 Tempering is required at 620°C minimum.

TABLE 6.3
RECOMMENDED HOLDING TEMPERATURES FOR SOLUTION
ANNEALING OF GROUPS K AND M STEELS

Material group (See Section 2)	Material type	Typical nominal composition (and types)	Holding temperature °C (see Note)
K	Austenitic chromium-nickel steel	18 Cr-8 Ni (302, 304); 23 Cr-12 Ni (309); 25 Cr-20 Ni (310); 18 Cr-10 Ni-Ti (321); 19 Cr-10 Ni-Nb (347)	1010–1095
		18 Cr-10 Ni-2 Mo (316)	1010–1120
		309 Nb, 310 Nb, 316 Nb	1010–1065
M	Ferritic- austenitic chromium-nickel steel	22Cr-5Ni-3Mo (S31803)	1020–1100

NOTE: Where the method of heating suggested in Clause 14.6.2 is used, particular care is necessary to ensure that the requirements of Clause 14.10 are satisfied.

TABLE 6.4
HOT WORKING AND ANNEALING OF NON-FERROUS METALS

Material group (See Section 2)	Material type and AS or ASTM grades	Recommended hot-working temperatures		Recommended annealing		
		For light work °C	For heavy work °C	Temperature °C	Time at temperature min	
ALUMINIUM AND ALUMINIUM ALLOYS						
A1 21	1080A 1060 1050 1100 1200 3003	Up to 200	200–400	350 350 350 350 350 410	Note 3	
A1 22	3203 5052 5154 5251 5454			410 350 350 350 350		
	5083} 5086}	Refer to material supplier for recommendation	Refer to material supplier for recommendation	350 350		
A1 25	6061} 6063} (Notes 1 and 2)	Up to 200	200–400	410		120–180
COPPER AND COPPER ALLOYS						
Cu 31	99Cu (Deoxidized)	760		370–660	15–30	
Cu 32	Admiralty brass Aluminium brass Naval brass Muntz (60/40- Pb)	650 760 650 620	790 870 820 790	430–590 430–590 430–590 430–590	15–30 15–30 15–30 15–30	

(continued))

TABLE 6.4 (continued)

Material group (See Section 2)	Material type and AS or ASTM grades	Recommended hot-working temperatures		Recommended annealing	
		For light work °C	For heavy work °C	Temperature °C	Time at temperature min
Cu 34	Copper-Nickel (70/30)	930	1090	650–870	15–30
	Copper/Nickel (90/10)	760	980	590–820	15–30
Cu 35	Aluminium bronze	760–870	820–930	760–820	15–60
	Aluminium bronze	790	870	680–730	15–30
	Copper silicon	700	870	480–700	15–30
NICKEL AND NICKEL ALLOYS (Note 4)					
Ni 41	Nickel	540–650	650–1260		
	Low carbon nickel	540–650	650–1260		
Ni 42	Nickel copper	650–930	927–1180		
Ni 43	Ni-Cr-Fe	870–1010	1010–1260		
Ni 46	Ni-Fe-Cr	870–1010	1010–1260		
TITANIUM AND TITANIUM ALLOYS					
Ti 51, 52	Titanium unalloyed	—	320 max.		

NOTES:

- 1 Annealed and as-rolled tempers—for T5 and T6 tempers, 149°C–177°C.
- 2 Annealed and as-rolled tempers—for T5 and T6 tempers, 177°C–204°C.
- 3 Attainment of annealing temperature is of more consequence than annealing time. Cooling rate is unimportant.
- 4 Furnace atmospheres should not contain more than 0.07 g of sulfur per 1.0 m³ at standard temperature and pressure conditions.

6.3 COLD FORMING OF PRESSURE EQUIPMENT COMPONENTS FROM PLATES AND SECTIONS

6.3.1 Ferritic steels—Plates and sections—Material groups A to G Steel plates shall be formed by rolling or pressing and shall not be formed cold by blows.

Pressure parts in groups A to E steels inclusive, which have been formed by cold dishing, flanging or rolling or by local heating methods causing fibre strain greater than 5% as calculated by Equations 6.3(1), 6.3(2) or 6.3(3) shall be heat treated in accordance with Section 14 where any of the following conditions also apply:

- (a) The equipment will contain lethal substances, either liquid or gaseous as defined by AS 4343.
- (b) The material requires impact testing by the pressure equipment Standard.
- (c) The thickness of the part before cold forming exceeds 16 mm.
- (d) The reduction by cold forming from as-rolled thickness is more than 10 percent.
- (e) The temperature of the material during forming is in the range of 120°C to 480°C.

Unless the manufacturer carries out adequate tests to prove that stress relieving heat treatment will restore satisfactory material properties, normalizing is the preferred heat treatment method for—

- (i) components subject to double curvature forming involving reverse bending or significant stretching;
- (ii) cold spun ends or other components subject to progressive forming; and
- (iii) alloy steel (i.e. groups B to E inclusive) components in Class 1 pressure vessels.

Dimensional correction after heat treatment by cold forming is permitted provided that extreme fibre strain does not exceed five percent as calculated by Equations 6.3(1), 6.3(2) or 6.3(3) as applicable. Normalizing shall be carried out using times and temperatures as specified in Table 6.2 for the relevant alloy.

Groups F and G steels subject to forming in which the extreme fibre strain exceeds five percent shall be heat treated in accordance with Table 6.2 and tests shall be carried out in accordance with Clause 14.18 to prove that the material has the required properties.

The percentage of extreme fibre strain shall be determined by Equations 6.3(1), 6.3(2) or 6.3(3) as appropriate. The selection of the appropriate equation is a function of the forming operation and shape of the final part which governs its classification into single curvature (e.g. cylinders) or double curvature (e.g. dished ends, deep drawing operations).

For double curvature (e.g. dished ends)—

$$\text{Strain (\%)} = \frac{75t}{R_f} \left(1 - \frac{R_f}{R_o} \right) \quad \dots 6.3(1)$$

For single curvature (e.g. cylinders or cones)—

$$\text{Strain (\%)} = \frac{50t}{R_f} \left(1 - \frac{R_f}{R_o} \right) \quad \dots 6.3(2)$$

where

t = nominal plate thickness, in millimetres

R_f = final outside radius, in millimetres

R_o = original inside radius (equals infinity for flat plate), in millimetres

For dished ends, the strain may alternatively be determined by—

$$\text{Strain (\%)} = 100 \ln \left(\frac{D_b}{D_e - 2t} \right) \quad \dots 6.3(3)$$

where

t = nominal thickness of the initial blank, in millimetres

D_b = the diameter of the blank or the diameter of the intermediate component, in millimetres

D_e = external diameter of the final component, in millimetres

$\ln$ = natural logarithm

6.3.2 Austenitic and austenitic-ferritic steels (groups K and M steels) Austenitic stainless (group K) steels for use at minimum design temperatures of -196°C and above may be cold formed without any subsequent heat treatment, provided heat treatment for corrosion resistance is not specified by the purchaser and the following conditions are applicable:

- (a) When the specified minimum elongation is $\geq 30\%$ and a level of 15% cold deformation is not exceeded, or the residual elongation after cold forming is demonstrated to be $\geq 15\%$.
- (b) With levels of cold forming above 15%, proof is provided in individual cases that the residual elongation after cold forming is at least 15%.
- (c) For cold formed ends (semi-elliptical, torispherical and hemispherical) the material certificate for the base material (prior to cold forming) shows the following values for elongation:
 - $\geq 40\%$ for wall thickness ≤ 15 mm
 - $\geq 45\%$ for wall thickness > 15 mm

All elongation percentages quoted above for materials as supplied are based on gauge length equal to five times test piece diameter.

For Items (a) and (b) the level of deformation shall be determined from Equations 6.3(1), 6.3(2) or 6.3(3) as appropriate.

Austenitic chromium-nickel steels (group K) for use at minimum design temperatures below -196°C and ferritic-austenitic chromium-nickel steels (group M) may be cold formed provided that they are subsequently fully softened and descaled where the extreme fibre strain exceeds 10%. This heat treatment may be omitted, by agreement between the manufacturer and purchaser, for strains up to 15% where tests show that—

- (i) the extent of cold working is insufficient to reduce the corrosion resistance or notch toughness below acceptable limits or reduce elongation below 15%; or
- (ii) where unacceptable distortion would result from heat treatment.

When the conditions in Item (a) or (b) are not met, full softening of group K and M steels is required, and shall be done by a heat treatment in accordance with Table 6.3.

6.3.3 Non-ferrous metals Non-ferrous metals may be cold formed by rolling, pressing or spinning. Relatively small local bulges and buckles may be removed by hammering.

6.3.4 Plates welded prior to cold forming It is recommended that cold forming of plates, welded together prior to forming which results in the weld being cold strained, shall be limited to the materials and thicknesses as listed in Table 6.5.

Prior to cold forming, the weld reinforcement shall be ground flush.

Where any part of a welded joint has been strained in excess of 0.5 percent, that portion of the weld shall be examined by radiographic or ultrasonic methods, and in addition groups A2 to M steels shall be inspected for cracks by magnetic particle or penetrant methods, except where the manufacturer adopts alternative procedures proven by extensive experience.