

Australian/New Zealand Standard™

Pressure equipment—Welding and brazing qualification



AS/NZS 3992:2015

This Joint Australian/New Zealand Standard was prepared by Joint Technical Committee ME-001, Pressure Equipment. It was approved on behalf of the Council of Standards Australia on 24 July 2015 and on behalf of the Council of Standards New Zealand on 7 August 2015.

This Standard was published on 31 August 2015.

The following are represented on Committee ME-001:

Australasian Corrosion Association
Australasian Institute of Engineer Surveyors
Australian Aluminium Council
Australian Chamber of Commerce and Industry
Australian Industry Group
Australian Institute for the Certification of Inspection Personnel
Australian Institute of Energy
Australian Institute of Petroleum
Bureau of Steel Manufacturers of Australia
Department of Justice and Attorney General, Qld
Electricity Engineers Association, New Zealand
Energy Networks Association
Engineers Australia
Institution of Professional Engineers New Zealand
Materials Australia
National Association of Testing Authorities Australia
New Zealand Heavy Engineering Research Association
New Zealand Manufacturers and Exporters Association
Welding Technology Institute of Australia
WorkCover New South Wales
WorkSafe Division, Department of Commerce, WA
WorkSafe New Zealand
WorkSafe Victoria

Keeping Standards up-to-date

Standards are living documents which reflect progress in science, technology and systems. To maintain their currency, all Standards are periodically reviewed, and new editions are published. Between editions, amendments may be issued. Standards may also be withdrawn. It is important that readers assure themselves they are using a current Standard, which should include any amendments which may have been published since the Standard was purchased.

Detailed information about joint Australian/New Zealand Standards can be found by visiting the Standards Web Shop at www.saiglobal.com.au or Standards New Zealand web site at www.standards.co.nz and looking up the relevant Standard in the on-line catalogue.

For more frequent listings or notification of revisions, amendments and withdrawals, Standards Australia and Standards New Zealand offer a number of update options. For information about these services, users should contact their respective national Standards organization.

We also welcome suggestions for improvement in our Standards, and especially encourage readers to notify us immediately of any apparent inaccuracies or ambiguities. Please address your comments to the Chief Executive of either Standards Australia or Standards New Zealand at the address shown on the back cover.

This Standard was issued in draft form for comment as DR 100853.

Australian/New Zealand Standard™

Pressure equipment—Welding and brazing qualification

Originated in Australia as AS 3992—1992.
Originated in New Zealand as AS/NZS 3992:1998.
Third edition 2015.

COPYRIGHT

© Standards Australia Limited/Standards New Zealand

All rights are reserved. No part of this work may be reproduced or copied in any form or by any means, electronic or mechanical, including photocopying, without the written permission of the publisher, unless otherwise permitted under the Copyright Act 1968 (Australia) or the Copyright Act 1994 (New Zealand).

Jointly published by SAI Global Limited under licence from Standards Australia Limited, GPO Box 476, Sydney, NSW 2001 and by Standards New Zealand, Private Bag 2439, Wellington 6140.

ISBN 978 1 76035 227 1

PREFACE

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee ME-001, Pressure Equipment, to supersede AS/NZS 3992:1998, *Boilers and pressure vessels—Welding and brazing qualification*.

The objective of this Standard is to reduce misunderstanding, costs and delays in qualifying welding, avoid unnecessary duplication of testing, promote greater confidence in reciprocal acceptance of approved procedures, and improve safety. It also aims for greater alignment with ASME and ISO Standards, and to be consistent with the current work health and safety laws.

This Standard unifies and revises the requirements for the qualification of welding and brazing procedures, welding and brazing personnel, and production test plates and welds, specified in AS 1210, *Pressure vessels*, AS 1228, *Pressure equipment—Boilers*, and AS 4041, *Pressure piping*.

This Standard is a major revision of AS/NZS 3992:1998 based on AS 1210, with due allowance for latest practices or requirements of AS 1210, AS 1228 and AS 4041. Modifications have been made to utilize current appropriate requirements of ASME BPVC-IX, ISO 9606 (all parts), ISO 15607 and AS 2885.2.

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

The main changes in this revision are as follows:

- (a) Extension of pre-qualified welding procedures.
- (b) Relaxation of bend test requirement.
- (c) Addition of temper bead welding.
- (d) Significant changes to weld production tests to align more closely with world practice and cover requirements for AS 1210 and AS 1228.
- (e) Addition of thermocouple attachments qualification.
- (f) Addition of general guidance on qualification of welding non-metallic material to cater for their wider use.
- (g) Addition of special treatment of welds.
- (h) Updating of referenced documents and alignment with current editorial practices.

It is not intended that the publication of this edition will invalidate welding tests that were accepted in respect of other Standards referenced in AS/NZS 1200, *Pressure equipment*.

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

CONTENTS

	<i>Page</i>
SECTION 1 SCOPE AND GENERAL	
1.1 SCOPE.....	7
1.2 APPLICATION	9
1.3 REFERENCED DOCUMENTS.....	9
1.4 DEFINITIONS.....	9
1.5 OTHER PROCESSES	11
1.6 OTHER MATERIALS.....	11
1.7 WELDING AND BRAZING TEST PIECES—SUPERVISION.....	11
SECTION 2 PREQUALIFIED WELDING PROCEDURES	
2.1 GENERAL.....	12
2.2 PREQUALIFIED GASES.....	13
2.3 ALUMINOTHERMIC WELDING.....	13
2.4 THERMOCOUPLE ATTACHMENT WELDS	13
SECTION 3 QUALIFICATION OF WELDING PROCEDURES FOR BUTT, BRANCH AND FILLET WELDS	
3.1 GENERAL.....	15
3.2 METHODS OF QUALIFICATION OF WELDING PROCEDURE.....	15
3.3 RECORDING OF WELDING PROCEDURE DATA	15
3.4 TESTING OF WELDING PROCEDURE TEST WELDS.....	15
3.5 REQUALIFICATION OF A WELDING PROCEDURE.....	16
3.6 PORTABILITY OF QUALIFIED WELDING PROCEDURES	16
3.7 WELDING PROCEDURE SPECIFICATION FOR NEW PRESSURE EQUIPMENT	16
3.8 WELDING PROCEDURES FOR REPAIR WELDING	16
3.9 REPAIRS, REPLACEMENT OR ALTERATION TO IN-SERVICE PRESSURE EQUIPMENT	17
3.10 WELDING PROCEDURE FOR TUBE AND TUBESHEET WELDING	17
SECTION 4 ITEMS TO BE RECORDED FOR WELDING PROCEDURE TEST WELDS	
4.1 GENERAL.....	18
4.2 ITEMS SPECIFIC TO NOMINATED WELDING PROCESSES	18
4.3 RECORDING OF WELDING PROCEDURE TEST WELDS.....	18
SECTION 5 ESSENTIAL VARIABLES FOR WELDING PROCEDURE QUALIFICATION	
	20
SECTION 6 WELD TEST PIECES	
6.1 TEST PIECES	48
6.2 VISUAL EXAMINATION.....	50
6.3 NON-DESTRUCTIVE EXAMINATION OF TEST PIECES.....	50
6.4 POSTWELD HEAT TREATMENT	50

SECTION 7 MECHANICAL TESTING OF WELDS FOR PROCEDURE QUALIFICATION	
7.1	GENERAL..... 55
7.2	RESPONSIBILITY FOR TESTING..... 55
7.3	TEST SPECIMENS 55
7.4	TRANSVERSE TENSILE TEST..... 55
7.5	ALL-WELD-METAL TENSILE TEST 56
7.6	BEND TEST 56
7.7	CHARPY V-NOTCH IMPACT TEST..... 58
7.8	MACRO EXAMINATION 64
7.9	WELD JOINT HARDNESS TEST 64
7.10	FILLET BREAK TEST 65
7.11	NICK-BREAK TEST..... 65
7.12	ADDITIONAL TESTS BEFORE REJECTION..... 65
7.13	REPORTING OF RESULTS 66
SECTION 8 PROCEDURE QUALIFICATION FOR SPECIAL WELDS	
8.1	CLAD PLATE WELDING 67
8.2	CORROSION-RESISTANT WELD METAL OVERLAY 67
8.3	HARD FACING (WEAR RESISTANT) WELD METAL OVERLAY 68
8.4	TEMPER BEAD WELDING 70
8.5	TUBE TO TUBE PLATE WELDING 75
SECTION 9 WELDER QUALIFICATION	
9.1	GENERAL..... 76
9.2	METHODS OF QUALIFICATION..... 76
9.3	EXTENT OF APPROVAL OF WELDER QUALIFICATION 76
9.4	INFORMATION FOR WELDER FOR QUALIFICATION TEST WELDS..... 76
9.5	EXAMINATION AND TESTING OF WELDER QUALIFICATION TEST WELDS 77
9.6	RECORDING OF WELDER QUALIFICATION TESTS 77
9.7	RETESTS 78
9.8	RENEWAL OF WELDER QUALIFICATION..... 82
SECTION 10 WELD PRODUCTION TESTS	
10.1	PRODUCTION TEST PLATES 84
10.2	EQUIPMENT REQUIREMENTS OF PRODUCTION TEST PLATES 84
10.3	NUMBER OF PRODUCTION TEST PLATES..... 85
10.4	PREPARATION OF PRODUCTION TEST PLATES..... 85
10.5	PRELIMINARY EXAMINATION OF TEST PLATES 86
10.6	TREATMENT OF TEST PLATES 86
10.7	TESTING OF TEST PLATES 86
10.8	ADDITIONAL TESTS BEFORE REJECTION..... 86
10.9	RECORDS..... 86
SECTION 11 BRAZING QUALIFICATION	
11.1	GENERAL..... 88
11.2	QUALIFICATION REQUIRED..... 88
11.3	GROUPING OF MATERIALS FOR BRAZING QUALIFICATION..... 88
11.4	GROUPING OF BRAZING FILLER METALS 89
11.5	BRAZING FLOW POSITIONS..... 90
11.6	RECORDS..... 90

SECTION 12 QUALIFICATION OF BRAZING PROCEDURE	
12.1	GENERAL..... 92
12.2	REQUALIFICATION OF A BRAZING PROCEDURE..... 92
12.3	PORTABILITY OF QUALIFIED BRAZING PROCEDURE 92
12.4	PREQUALIFIED BRAZING PROCEDURE..... 92
12.5	ITEMS TO BE RECORDED FOR BRAZING PROCEDURE QUALIFICATION TEST BRAZES..... 93
12.6	ESSENTIAL VARIABLES FOR BRAZING PROCEDURE QUALIFICATION 93
12.7	TEST PIECES FOR BRAZING PROCEDURE QUALIFICATION..... 93
12.8	VISUAL EXAMINATION 93
SECTION 13 EXAMINATION AND TESTING OF BRAZED JOINTS	
13.1	REMOVAL OF TEST SPECIMENS 99
13.2	TRANSVERSE TENSILE TEST 99
13.3	BEND TEST 100
13.4	PEEL TEST 100
13.5	SECTIONING TEST 101
13.6	WORKMANSHIP SPECIMEN TEST 101
13.7	RETESTS 102
SECTION 14 BRAZER AND BRAZING OPERATOR QUALIFICATION	
14.1	METHODS OF QUALIFICATION 103
14.2	ESSENTIAL VARIABLES FOR QUALIFICATION OF BRAZING PERSONNEL 103
14.3	EXTENT OF APPROVAL OF BRAZING QUALIFICATION 103
14.4	INFORMATION TO BE GIVEN TO BRAZER OR BRAZING OPERATOR FOR QUALIFICATION TEST JOINT 103
14.5	QUALIFICATION TEST JOINTS AND TESTING 103
14.6	RECORDING OF BRAZER AND BRAZING OPERATOR QUALIFICATION TESTS 104
14.7	RETESTS 104
14.8	RENEWAL OF BRAZER QUALIFICATION 104
SECTION 15 ALUMINOTHERMIC WELDING OF ELECTRICAL CONDUCTORS	
15.1	PREQUALIFIED WELDING PROCEDURE..... 106
15.2	PROCEDURE QUALIFICATION..... 106
15.3	PRODUCTION TEST 106
SECTION 16 THERMOCOUPLE ATTACHMENT JOINTS	
16.1	GENERAL..... 107
16.2	PREQUALIFICATION PROCEDURES 107
16.3	TEST JOINT..... 107
16.4	PROCEDURE QUALIFICATION TESTS 107
16.5	QUALIFICATION OF OPERATOR 108
SECTION 17 WELDING QUALIFICATION OF NON-METALLIC MATERIALS	
17.1	SCOPE..... 109
17.2	GENERAL REQUIREMENTS..... 109
SECTION 18 SPECIAL TREATMENT OF WELDS	
18.1	SCOPE..... 110
18.2	PROCEDURE..... 110

APPENDICES

A	LIST OF REFERENCED DOCUMENTS.....	111
B	WELDING PROCEDURE SPECIFICATION (WPS)	115
C	WELDING PROCEDURE QUALIFICATION RECORD (PQR).....	118
D	TYPICAL FERROUS MATERIAL SPECIFICATIONS	121
E	MACRO-ETCHING OF WELDED JOINTS	124
F	BRAZING PROCEDURE QUALIFICATION RECORD.....	125
G	BASIS FOR GROUPING OF MATERIALS	127
H	EXAMPLES OF THE APPLICATION OF THIS STANDARD TO PRESSURE VESSEL AND PIPING MANUFACTURER	131

STANDARDS AUSTRALIA/STANDARDS NEW ZEALAND

Australian/New Zealand Standard**Pressure equipment—Welding and brazing qualification**

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE

This Standard specifies requirements for the qualification of welding and brazing procedures, welders and brazers, and requirements for production weld testing other than non-destructive examination, when used in the manufacture, alteration and repair of boilers, pressure vessels, pressure piping and their components as specified in AS/NZS 1200, AS 1210, AS 1228 and AS 4041. See Figure 1 for a summary of the welding and brazing qualification process.

This Standard is intended for use by designers, manufacturers, welders, brazers, inspection bodies, inspectors, testing authorities and all persons concerned with the welding and brazing of pressure equipment.

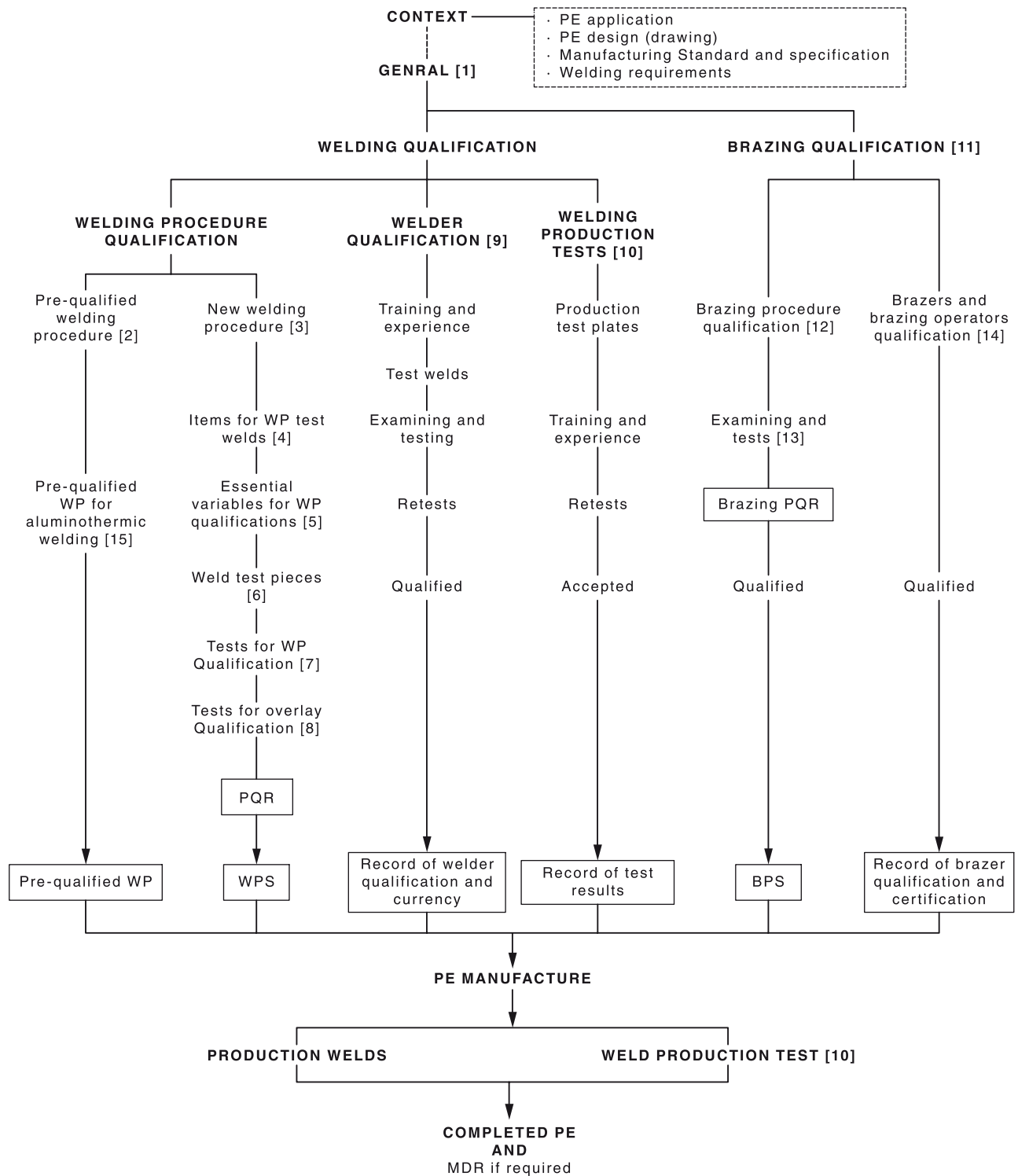
This Standard may apply to automotive LP Gas fuel vessels (covered by AS/NZS 3509), serially produced pressure vessels (covered by AS 2971) or welded gas cylinders (covered by AS 2030.1), where specified by these Standards. This Standard does not apply to pipelines in accordance with AS 2885.2, except where referenced.

The Standard provides specific details for the following:

- (a) Manual metal-arc welding, flux cored arc welding, gas metal-arc welding, gas tungsten-arc welding, submerged arc welding, plasma arc welding, electroslag welding and oxy-acetylene welding.
- (b) Torch brazing, furnace brazing, induction brazing, resistance brazing and dip brazing.
- (c) The welding and brazing of carbon, carbon-manganese, and low and high alloy steels; and copper, aluminium, nickel, titanium, zirconium and alloys of these materials.

Specific details for stud welding, electron-beam welding, explosion welding, laser beam welding, electro-gas welding, fusion welding of plastics and friction welding processes are not covered by this Standard. For these, see ASME BPVC-IX or equivalent.

The principles established in this Standard may be used in the qualification of processes, materials and applications not covered by the scope outlined above (see also Clause 1.5 and Clause 1.6).



LEGEND

[X] Numbers in brackets identify relevant section in this Standard

FIGURE 1.1 SUMMARY OF WELDING AND BRAZING QUALIFICATION PROCESS

1.2 APPLICATION

Where there are differences between this Standard and AS 1210, AS 1228 or AS 4041, the requirements of this Standard apply.

Where this Standard makes reference to other Standards, these referenced Standards are not intended to be limiting or exclusive and other equivalent national standards acceptable to the parties concerned may be substituted for the referenced Standards. AS/NZS 1200 provides a list of pressure equipment Standards used in Australia and New Zealand.

Compliance with ASME BPVC-IX, ISO 15607, ISO 9606 (Parts 1 and 2) or ISO 15614-1 is deemed to be an acceptable alternative to the requirements of this Standard where agreed between fabricator and purchaser. Where this Standard (AS/NZS 3992) requires tests not already completed under these ASME and ISO Standards, then this can be covered by those additional tests only, rather than repeating the full set of tests, for example, as part of a production test plate.

Users of this Standard are reminded that it has no legal authority in its own right, but may acquire legal standing in one or more of the following circumstances:

- (a) Adoption by a government or other authority having jurisdiction.
- (b) Adoption by a purchaser as the required standard of construction when placing a contract.
- (c) Adoption where a manufacturer states that pressure equipment is in accordance with an application Standard which mandates compliance with this Standard.

1.3 REFERENCED DOCUMENTS

The documents referred to in this Standard are listed in Appendix A.

Where reference is made to a Standard by its number only, the reference applies to the current edition of the Standard. Where reference is made to a Standard by number, year and, where relevant, an amendment number, the reference applies to that specific document.

1.4 DEFINITIONS

For the purpose of this Standard, the definitions in AS 2812 and those below apply.

1.4.1 Brazer

A person who performs a manual brazing operation.

1.4.2 Brazing operator

A person who operates furnaces or other automatically controlled or timed brazing equipment.

1.4.3 Essential variables (for a welder qualification)

Those variables in the welding procedure in which a change outside the limits specified in this Standard is considered to reduce the ability of a welder to make a weld with the required mechanical properties and soundness, (e.g. change in welding process or technique, or the omission of a backing strip, bar or ring).

1.4.4 Essential variables (for a welding or brazing procedure)

Those variables in the welding or brazing procedure in which a change outside the limits specified in this Standard is considered to affect the mechanical properties of the weld, (e.g. change in welding process, consumables, or heat treatment).

1.4.5 Inspection body

A body corporate or firm responsible for inspection which may be any one or more of design verification, manufacture inspection and in-service inspection.

NOTES:

- 1 The manufacturer may be the inspection body when permitted by AS 3920.
- 2 In New Zealand, inspection bodies are required to be accredited, and also approved by WorkSafe NZ.

1.4.6 Inspector

A person employed by, or acceptable to, the inspection body for the purpose of inspecting pressure components in accordance with this Standard.

1.4.7 Manufacturer

The person or organization responsible for the manufacture, welding and testing of pressure equipment. A manufacturer may also be the designer.

NOTE: In this Standard, 'manufacturer' includes 'fabricator', 'constructor', 'assembler', 'installer', 'erector' and 'repairer'. The term 'manufacturer' is used to embrace all or some of these terms and is applicable to all locations, on or off site, where components are welded or brazed. It also includes a manufacturer's authorized representative.

1.4.8 Metallurgical properties

Metallurgical properties are the material properties, such as tensile strength, yield strength, impact toughness and metallurgical structure.

1.4.9 Postweld heat treatment (stress relief)

Uniform heating of pressure equipment or portion thereof to a sufficient temperature below the critical range, followed by uniform cooling, the intent of which is to modify the metallurgical properties and/or to relieve the major portion of the residual stresses.

1.4.10 Prequalified welding procedure

A documented welding procedure satisfying the requirements of Section 2. It has the same standing as a qualified welding procedure when used within the limits specified in Section 2.

1.4.11 Pressure equipment

Boilers, pressure vessels, pressure piping and their components covered by AS/NZS 1200.

1.4.12 Procedure qualification record (PQR)

A document recording test variables and test results to establish a welding procedure.

1.4.13 Qualified welding procedure

A welding procedure which has been conducted, tested, assessed, documented and verified as complying with the requirements of this Standard.

NOTE: This definition is intended to include the use of prequalified welding procedures as detailed in Section 2.

1.4.14 Shall

Indicates a requirement.

1.4.15 Should

Indicates a recommendation.

1.4.16 Sound or soundness

A weld or braze that is free from unacceptable imperfections (defects).

1.4.17 Temper bead welding

The welding of a bead at a specific location on a weld for the purpose of improving the metallurgical properties of the heat-affected zone of the previously deposited weld metal.

1.4.18 Test piece

Components welded together in accordance with a specified welding procedure, or a portion of a welded joint detached from a structure, for test.

1.4.19 Test specimen

A portion detached from a test piece and prepared, as required, for testing.

1.4.20 Welder qualification test

A documented test, carried out by a welder, working to an approved welding procedure, to determine the welder's ability to deposit sound weld metal using the manufacturer's available equipment.

1.4.21 Welding procedure specification (WPS)

A documented qualified welding procedure prepared to provide direction for making production welds to the requirements of this Standard (see also Clause 1.4.13).

1.4.22 Welding procedure test

The making and testing of a welded joint representative of that to be used in production in order to prove the weldment is capable of providing the required properties for its intended application.

1.4.23 Weld production test

The making and testing of a representative sample of production welds to check the quality of welds during the manufacture of pressure equipment.

1.5 OTHER PROCESSES

This Standard does not prohibit the use of processes not specifically listed in Clause 1.1. Where another process is to be used, it shall give a result at least equal to that set by this Standard.

1.6 OTHER MATERIALS

Materials not specified in Clause 1.1(c) may be welded in accordance with this Standard provided the welding method gives a result at least equal to this Standard.

1.7 WELDING AND BRAZING TEST PIECES—SUPERVISION

Welding for assessment of welding or brazing procedure and welder and brazer qualification shall be supervised by a person who is a supervisor to AS 1796 Certificate 10 or equivalent.

SECTION 2 PREQUALIFIED WELDING PROCEDURES

2.1 GENERAL

Welding procedure qualification testing is not required for welding procedures classified as 'prequalified' in accordance with this Clause 2.1.

Welding procedures which comply with Table 2.1 shall be deemed to be prequalified and do not require further qualification in accordance with Sections 3 to 7, provided that—

- (a) each procedure is documented in accordance with the applicable requirements of Appendix B;
- (b) each procedure has a signed endorsement by the manufacturer (see Appendix B);
- (c) each procedure is only applicable within the limits of the essential variables listed in Table 5.1 but not Table 5.4 which does not apply to prequalified procedures; and
- (d) each procedure has been used by a welder (named) employed by the manufacturer and who has met the requirements of a welder qualification test (date given) in accordance with Clause 9.2.

The use of prequalified welding procedures does not relieve the manufacturer of any responsibilities, in respect of the provisions of this Standard, for welder qualification and weld production testing.

NOTE: 'Prequalified welding procedures' are known as 'Standard welding procedure specifications' in ASME BPVC and ISO Standards.

TABLE 2.1
CONDITIONS FOR PREQUALIFIED WELDING PROCEDURES

Item	Range of application
Pipe diameter	All diameters
Plate or pipe thickness (nominal)	3 mm to 40 mm thickness
Parent metal group	A1 and A2 as welded or with PWHT, K1 as welded
Carbon equivalent (see Note 1)	0.45% maximum based on actual or specified values
Welding processes	Manual metal-arc, submerged arc, gas tungsten-arc welding, flux cored arc welding, gas metal arc (spray transfer) or combination of these processes
Design minimum temperature	Equal to and above 0°C
Welding consumables	Table 2.2 and Clause 2.2
Weld preparation	Table 2.3
Welding position	Figure 5.1
Welding current, voltage and polarity	In accordance with consumable supplier's requirements and recommendations
Preheat temperature	Above 0°C and in accordance with the pressure equipment Standard (see Note 3)
Travel speed	Runout length for manual electrodes ≤ 1 (see Note 2). Submerged arc welding between 200 mm/min and 600 mm/min
Initial and interrun cleaning	Free from any materials which may impair the weld quality
Storage and handling of welding consumables	In accordance with the pressure equipment Standard and the consumable supplier's requirements and recommendations
Post weld heat treatment	In accordance with AS 4458

NOTES TO TABLE 2.1:

$$1 \quad \text{Carbon equivalent} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15} \text{ percent.}$$

Where heat analysis of all of the above elements is not quoted, the value of $C + \frac{Mn}{6} = 0.42$ percent maximum applies.

$$2 \quad \text{Runout length} = \frac{\text{length of weld run}}{\text{length of electrode consumed}}.$$

3 Preheat should also comply with AS 4458, EN 1011-2 or WTIA Technical Note 1.

TABLE 2.2
PREQUALIFIED WELDING CONSUMABLES (see Notes 1 and 2)

1	2	3	4	5	6	7
Material group (see Table 5.3)	Manual metal-arc (AS/NZS 4855)		Submerged arc (AS/NZS ISO 14171, AS/NZS ISO 14174)	Flux-cored arc (AS/NZS ISO 17632)	Gas metal arc (AS/NZS 14341, AS/NZS 21952, AS/NZS 16834) (ISO 14341)	Gas tungsten arc (AS/NZS 1167.2) (ISO 636)
A1	A-E35 3 A-E38 3 A-E42 3					
A2 (see Note 3)	A-E35 3 A-E38 3 A-E42 3	B-E43X6 U B-E43X8 U B-E49X5 U B-E49X6 U B-E49X8 U	403Y W503Y	A-T35 3 A-T38 3 A-T42 3 B-T433U B-T493U	W503 A-G35 3 A-G38 3 A-G42 3 B-G43 3U B-G49 3U	A-W35 3 A-W38 3 A-W4 3 B-W43 3U B-W49 3U
K1	See Note 4					

NOTES:

- Consumables for material Group A2 are suitable for Group A1 materials.
- Consumables with a higher impact grading than that shown or equivalent complying with ASME BPVC-IIC are acceptable.
- For material Group A2, consumables of the A-E35, B-E43XX, W400Y, A-T35, B-T43, A-G35, B-G43, A-W35 or B-W43 type will equal or exceed the specified minimum yield strength of the material and will usually give a tensile strength of not less than 95% of the specified minimum tensile strength of the parent material. For steel to AS/NZS 3678-400, these consumables shall require qualification.
- Equivalent or alternative consumables complying with ASME BPVC-IIC and listed in Table 5.5.

2.2 PREQUALIFIED GASES

For GTAW welding, argon gas of 'welding quality' only shall be used for a prequalified welding procedure. The maximum impurity content shall not exceed 1 part in 2000 by volume (i.e. the gas shall be at least 99.95% pure).

For FCAW, shielding gases shall be as specified and qualified by the consumable manufacturer.

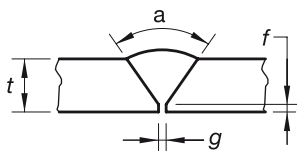
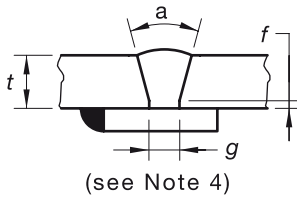
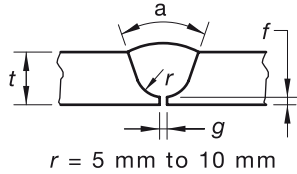
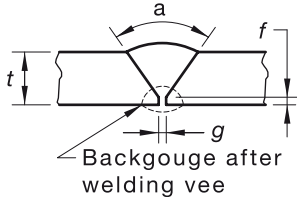
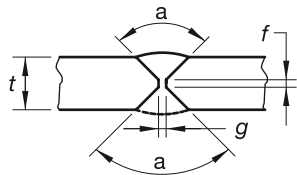
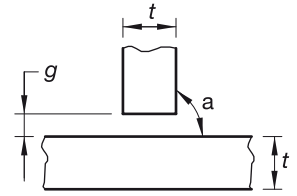
2.3 ALUMINOTHERMIC WELDING

For pre-qualified welding procedures of aluminothermic welding, see Section 15.

2.4 THERMOCOUPLE ATTACHMENT WELDS

For pre-qualified welding procedures of thermocouple attachment welds, see Section 16.

TABLE 2.3
ACCEPTABLE WELD PREPARATIONS FOR PREQUALIFIED
WELD PROCEDURES (see Notes 1 to 5)

Item	Joint type	Joint form (sectional view)	Dimensions of joint			
			Thickness (<i>t</i>), (max.) mm	Gap (<i>g</i>) mm	Bevel angle ($\angle$) degrees	Root face (<i>f</i>) mm
1	Single-welded single-V butt joint—full penetration		20	1.5–3	60–90	0–3
2	Single-welded single-V butt joint with backing strip—full penetration		20	5–10	15–45	0–3
3	Single-welded single-U butt joint—full penetration		20	0–3	20–40	0–3
4	Double-welded single-V joint back gouged—full penetration		20	0–3	60–90	0–3
5	Double-welded double-V joint— full penetration		40	0–3	60–90	0–3
6	Single or double welded fillet joint		40	0–2	80–120 on each side	—

NOTES:

- 1 All weld preparations are applicable to one of the welding processes (or combinations) permitted in Table 2.1.
- 2 Branch welds are qualified by butt welds using maximum parent metal thickness nominated for *t* above.
- 3 The use of minimum angle should be associated with maximum radius or gap and conversely the minimum radius or gap should be associated with the maximum angle.
- 4 Indicate in welding procedure specification whether backing strip has intermittent or continuous welds.
- 5 See AS 1210, AS 1228 and AS 4041 for other acceptable weld preparations.

SECTION 3 QUALIFICATION OF WELDING PROCEDURES FOR BUTT, BRANCH AND FILLET WELDS

3.1 GENERAL

With the exception of prequalified welding procedures (see Section 2), each welding procedure that is used in the manufacture of pressure equipment shall be qualified by the manufacturer in accordance with this Standard. Qualification is intended to demonstrate—

- (a) the suitability of the welding procedure for the material used in the construction;
- (b) that the weld can be made without unacceptable imperfection (defects) in the weld deposit and heat affected zone;
- (c) that the mechanical properties, such as strength, and if applicable fracture toughness and hardness, satisfy specified requirements; and
- (d) the manufacturer's organization and equipment is capable of successfully using this procedure.

Requirements to satisfy other parameters such as microstructure, corrosion resistance, fatigue or erosion for specific service requirements may be specified by the purchaser. Such requirements are outside of the scope of this Standard.

Only qualified welding procedures shall be used in the manufacture of pressure equipment.

NOTES:

- 1 The welding procedure qualification test may also be used to qualify a welder (see Section 9).
- 2 AS 3920 provides guidance for inspection bodies in relation to welding procedures.

3.2 METHODS OF QUALIFICATION OF WELDING PROCEDURE

Qualification of a welding procedure shall be carried out by one of the following methods:

- (a) The making and testing of a procedure test weld in accordance with the requirements of Sections 6 and 7.
- (b) Simultaneously with the welding and testing of a production test plate or pipe provided that testing is carried out in accordance with Section 7.
- (c) Using a prequalified welding procedure in accordance with Section 2.

Where option (b) above is used, production welds carried out in conjunction with the proving of a welding procedure which fails to meet the requirements of this Standard shall be rejected.

3.3 RECORDING OF WELDING PROCEDURE DATA

Each procedure shall be recorded in detail, by the manufacturer, with the results of qualification tests and these records shall be accessible to the inspector (and purchaser where required). Appendix C nominates the required information for a welding procedure qualification record (PQR).

3.4 TESTING OF WELDING PROCEDURE TEST WELDS

The type, number, and methods of tests required to prove the suitability of the welding procedure for the welding of joints in the components shall be in accordance with this Standard. Where necessary, additional tests may be required to assess corrosion resistance or other properties of a weld joint.

3.5 REQUALIFICATION OF A WELDING PROCEDURE

Provided that there are no changes in the essential variables (as listed in Section 5), a qualified welding procedure shall remain in force indefinitely. Requalification of a welding procedure is only required where there is any change in the essential variables as specified in Section 5.

However, this Standard does not invalidate previous welding procedure approvals made to former national Standards or specifications provided that the intent of the technical requirements is satisfied, and that the previous procedure approvals are relevant to the application and production work on which they are to be employed.

Also, where additional tests have to be carried out to make the approval technically equivalent, it is only necessary to do the additional tests on a test piece which should be made in accordance with this Standard.

3.6 PORTABILITY OF QUALIFIED WELDING PROCEDURES

A welding procedure qualified by one manufacturer shall be valid for use by a second manufacturer, provided that—

- (a) the original qualification tests were carried out in accordance with this Standard, and were fully documented;
- (b) the second manufacturer has adequate equipment and facilities and demonstrates successful welding of welder qualification tests or production tests using the procedure;
- (c) the application of the welding procedure is acceptable to both manufacturers and the purchaser; and
- (d) the welding procedure specification identifies the original and second manufacturer.

3.7 WELDING PROCEDURE SPECIFICATION FOR NEW PRESSURE EQUIPMENT

For production welding, a welding procedure specification shall be prepared listing all necessary information for production welds to be made to the requirements of this Standard. This specification shall include essential variables together with any acceptable ranges for such variables, and any other variables which may affect the soundness of the welded joint.

An example of the requirements for a welding procedure specification is given in Appendix B. Other methods of presentation of a welding procedure specification are acceptable provided that they contain all relevant information to satisfy the requirements of this Clause for production welds.

3.8 WELDING PROCEDURES FOR REPAIR WELDING

For new equipment, visual or non-destructive examination which reveals non-acceptable imperfections in the equipment that has not been subject to service environment shall be repaired. Such repair welding shall be carried out to the original welding procedure or, where this is not practicable, to a repair procedure approved to this Standard.

3.9 REPAIRS, REPLACEMENT OR ALTERATION TO IN-SERVICE PRESSURE EQUIPMENT

Where repairs, replacement, modifications or alterations are made by welding to pressure equipment that is or has been in service, the welding shall comply with the requirements of AS/NZS 3788 and AS 3873 (when applicable) and the following:

- (a) For material, which has not been damaged, the welding procedure shall be qualified in accordance with this Standard.
- (b) For material that has been damaged by creep, hydrogen embrittlement, temper embrittlement, fatigue, erosion, or other forms of deterioration as referenced in AS/NZS 3788, API 570 or API 571, a repair welding procedure shall only be effected after the cause of the deterioration has been ascertained and taken into account to ensure a satisfactory repair procedure. Such a welding procedure shall be capable of producing welds acceptable to the owner.
- (c) For hot tapping repair procedures, a similar approach to Item (b) shall be undertaken. In addition, all precautions shall be taken during the hot tapping repair procedures to ensure the safety of the welding personnel and the repair procedures have been adequately reviewed.

3.10 WELDING PROCEDURE FOR TUBE AND TUBESHEET WELDING

For the qualification of welding procedures for tube to tubesheet welding, see ASME BPVC-IX or ISO 15614-8.

SECTION 4 ITEMS TO BE RECORDED FOR WELDING PROCEDURE TEST WELDS

4.1 GENERAL

The following items shall be recorded for each welding procedure test:

- (a) Welding process or processes when more than one is used, in making a complete joint.
- (b) Parent metal specification and group number, thickness, and for pipe, the outside diameter or outside dimensions.
- (c) Weld joint detail, including sketch and weld deposit thickness for welding processes used.

NOTE: See Table 5.1, Note 8, Clause 7.8.2 and Appendix C for more information.

- (d) Initial and interrun method for cleaning, degreasing, etc.
- (e) Welding position and direction of weld travel.
- (f) Classification of welding consumables (filler metal material specification and size, flux and gas).
- (g) Preheating and interrun temperature ranges, including method and control.
- (h) Approximate number and arrangement of runs and welding sequence, including sketch and string or weave technique, as applicable.
- (i) Back gouging or reverse side treatment, when applicable.
- (j) Postweld heat treatment, temperature and holding time.
- (k) Special features applicable to a specific welding procedure not covered in Table 4.1.
- (l) Name of manufacturer responsible for carrying out the procedure test.
- (m) Name of welder performing the test weld.

4.2 ITEMS SPECIFIC TO NOMINATED WELDING PROCESSES

The items listed in Table 4.1, in relation to a specific welding process, shall be recorded for each welding procedure test in addition to those items in Clause 4.1.

4.3 RECORDING OF WELDING PROCEDURE TEST WELDS

A record of the welding procedure and test results shall be retained by the manufacturer. Appendix C lists the required details of the procedure qualification record (PQR) for the recording of welding procedure test welds.

TABLE 4.1
ITEMS SPECIFIC TO NOMINATED WELDING PROCESSES

Item to be recorded	Welding process (see Note)							
	MMAW	GTAW	GMAW	SAW	ESW	GW	FCAW	PAW
Amperage	X	X	X	X	X		X	X
Arc voltage	X	X	X	X	X		X	X
Wire feed speed			X	X	X		X	X
Travel speed or runout length of electrode	X	X	X	X	X		X	X
Current type and polarity	X	X	X	X	X		X	X
Welding flux				X	X			
Shielding gas and flow rate		X	X				X	X
Arc energy (when applicable)	X	X	X	X	X		X	X
Electrode stick out			X	X			X	X
Purging gas and flow rate		X	X				X	
Tungsten electrode (diameter and type)		X						
Nozzle diameter		X						X
Gas type and pressure						X		
Flame characteristic						X		
Number of electrodes and configuration				X	X			
Oscillation width and dwell periods					X			X
Slag depth					X			
Special baking temperature of electrodes	X							
Special baking temperature of flux				X	X			

LEGEND:

MMAW = manual metal-arc welding

GTAW = gas tungsten-arc welding

GMAW = gas metal-arc welding

SAW = submerged arc welding

ESW = electroslag welding

GW = oxy-acetylene (gas) welding

FCAW = flux cored arc welding

PAW = plasma transferred arc welding

X = item to be recorded when applicable

NOTE: For multi-wire arc processes, record details for each wire.

For runout length, see Note 2 of Table 2.1.

SECTION 5 ESSENTIAL VARIABLES FOR WELDING PROCEDURE QUALIFICATION

Essential variables in qualifying a welding procedure shall be as listed in Table 5.1.

When changes are made to a qualified welding procedure, the welding procedure shall be requalified when any of the changes to the essential variables, as listed in Table 5.1, are applicable. Changes to other items of Table 4.1 that are not classified as essential variables by Table 5.1 may be made to a qualified welding procedure without requalification.

The material grouping system, referred to in Tables 5.1 and 5.2 and throughout this Standard, is applied throughout the Australian pressure equipment Standards. Table 5.3 provides an outline of the classification of material groups.

NOTES:

- 1 The basis for the grouping of ferrous material is given in Appendix G.
- 2 Some examples of the application of essential variables to welding procedures for pressure equipment construction are given in Appendix H.

For essential variables for special welding processes, see Section 8.

TABLE 5.1
ESSENTIAL VARIABLES FOR WELDING PROCEDURE QUALIFICATION

Item	Essential variable
1 Parent material specification (see Note 1)	A change from a material group to any other material group or for a combination of material groups, as listed in Table 5.3, except as permitted in Table 5.2
2 Parent material and weld deposit thickness and form (for mixed processes see Item 6 below)	Parent material and weld deposit thicknesses outside the limits given in Table 5.4, where 't' is dependent on joint details as given in Table 5.6
3 Weld joint detail (see Note 4)	Omission of backing strip or consumable backing ring in a butt joint. For fillet welds, see Clause 6.1.2
4 Welding position and weld direction (see Note 5)	The following are essential variables: (a) When impact tests are not required, change to or from vertical down. (b) When impact tests are required, any change in fundamental welding position (flat, horizontal, vertical and overhead), or change in weld direction (see Figures 5.1 and 5.2). Testing in the maximum heat input position, i.e. vertical up in plate or 5G or 6G positions in pipe shall qualify for all positions.
5 Welding consumables	The following are essential variables: (a) For all welding processes, a change in the numerical grouping (F number) of an electrode or filler rod as shown in Table 5.5. (b) For ferrous metals only, an increase or decrease in the weld metal specified minimum strength outside the parent metal specified tensile strength range. (c) For ferrous metals only, a variation of the alloy content of the weld metal outside of the specified range of the welding consumables used in the procedure test, except that for— (i) carbon and carbon manganese steels the addition or deletion of 0.5% molybdenum from the weld metal composition shall not require requalification; and (ii) 3xx series austenitic Cr-Ni steels (K ₁ group) a change in weld metal composition shall not require requalification.

TABLE 5.1 (continued)

Item	Essential variable
	(d) For flux cored arc welding, any change in flux formulations (e.g. rutile, basic or metal core) other than that which varies iron powder content only (see Note 6). (e) For submerged arc welding— (i) a change in flux classification as listed in AS/NZS ISO 14171, AS/NZS ISO 14174 or other International Standard; or (ii) a change from a flux recommended for one to three weld runs to a multi-pass flux or vice versa. (f) A change in the nominal composition of a shielding or backing gas outside the range specified in AS 4882 or ISO 14175. (g) A decrease in gas flow rate of the shielding gas by more than 10%. (h) Deletion of a backing gas. (i) For GTAW a change from solid wire to flux cored wire or vice versa.
6 Welding process (see Note 7). For mixed processes, see Notes 2 and 3, Clause 7.8.2, Appendix C, Paragraph C2(h) and (m) and Figure C1	A change in welding processes or combination of welding processes
7 Welding energy input (see Note 8)	The following are essential variables: (a) For Groups F and G steels, an increase or decrease in arc energy greater than 15%. (b) For low temperature operation requiring impact testing of weld metal, an increase in arc energy greater than 15%. (c) For materials operating in their creep range and Group M materials, arc energy outside the range 1 to 3 kJ/mm. Refer to API 579-1/ASME FFS-1 for creep ranges. (d) For conditions other than Items (a), (b) or (c), an increase in arc energy greater than 80% or decrease in arc energy greater than 50%.
8 Welding current and polarity (see Note 9)	For all processes, any change in the type of welding current and polarity
9 Preheat and interrun temperature	The following are essential variables: (a) An increase in the maximum of more than 50°C— (i) for Groups F and G steels; or (ii) when impact tests are required on the weld or heat affected zone. (b) An increase of more than 100°C in preheat or interrun temperature for all other ferrous materials. (c) A decrease of more than 50°C in preheat or interrun temperature recorded on the PQR for all ferrous materials provided that the temperature is not less than that defined in Note 3 and that specified in the welding procedure specification.
10 Delayed cooling	Any change in the control of cooling rate after welding when specified in the qualified welding procedure
11 Postweld heat treatment	A change in postweld heat treatment which requires the deletion of postweld heat treatment; or the addition of postweld heat treatment within a temperature range

NOTES TO TABLE 5.1:

- 1 For Group K and M materials, requalification of a welding procedure is required when specific corrosion resistance tests are required or where parent metal impact tests are required by the pressure equipment Standard for cryogenic service. In such instances the procedure is only applicable to the stainless steel grade of material used in the procedure test. Refer to Appendix D for typical ferrous material specifications.
- 2 A change from flat to tubular form of product or vice versa is not an essential variable.
- 3 Where the parent metal thickness of the production weld differs from that used in the test weld adjustment shall be made to achieve a satisfactory cooling rate by complying with the preheats listed in the pressure equipment Standard, Welding Technology Institute of Australia Technical Note 1 or EN 1011-2.
- 4 Single or double V, J, U or bevel or a square butt may be changed without requalification provided the form of the weld preparation is in agreement with recommended joint detail as listed in the pressure equipment Standards. See Clause 6.1 for changes between butt, branch and fillet welds.
- 5 For the limits of deviation from fundamental welding positions, see AS 3545.
- 6 'All-positional' coating or flux core formulations do not require requalification for single position welds provided there is no designated increase in the deposited weld metal hydrogen content.
- 7 For multi-process procedures, each welding process may be approved separately or in combination with other processes. Similarly, one or more processes may be deleted from an approved welding procedure provided the joint thickness is within the thickness range of the remaining process or processes. See also Item 8, Table 9.1.
- 8 Welding energy input is determined from the following equation:

$$Q = \frac{60EI}{v \times 10^3}$$

where

- Q = welding energy input, in kJ/mm
 E = arc voltage, in volts (RMS value for a.c.)
 I = welding current, in amperes (RMS value for a.c.) per electrode
 v = welding speed, in mm/min

This equation only applies to MMAW, SAW, GMAW, GTAW, FCAW and for non-waveform controlled welding.

For waveform controlled welding, an increase in energy input may be determined by—

- (a) an increase in bead size (width × thickness); or
 - (b) a decrease in length of weld bead per unit length of electrode.
- 9 For GMAW and FCAW, this includes a change from spray arc, globular arc or pulsating arc to short-circuiting arc or vice versa.

TABLE 5.2
PROCEDURE QUALIFICATION OF OTHER MATERIAL GROUPS

Material group(s) of original qualified welding procedure	Other material groups or combinations of steel groups (see Note 1)
A1 to A1 A1 to A2 A2 to A2 A3 to A1, A2 or A3	A1 to A2 [see Note 2(b)], A2 to A2 (see Note 2) A1 to A1, A2 to A2 (see Note 2) A1 to A1, A1 to A2 Nil
B to B B to A2 or A1	B to A2 or A1
C to C C to B, A2 or A1	C to B, A2 or A1
D1 to D1	D1 to D2 (Note 3), D1 to C
D2 or D3 to D2 or D3 (Note 3) D2 to C, B, A2	D2 or D3 (Note 2) to C, B, A2 or A1 (Note 4)
K to A1, A2, B, C, D1, D2 or D3	K to any lower ferritic steel group provided nickel based alloy welding consumables are used (see Table 5.5)

NOTES:

- 1 Compliance with Item 5(b) of Table 5.1 is required.
- 2 Qualification of a welding procedure using A1 to A1 (or A1 to A2) as the steel group originally qualified is only permitted for A2 materials if—
 - (a) the test values of transverse tensile test, all weld metal tensile test, and notch bar impact tests, when required, exceed the minimum properties required for A2 group materials; and
 - (b) weld preheat temperatures are applied in accordance with the requirement of AS 4458 or WTIA Technical Note 1, (where a production test plate is required, other pre-heat temperatures are permitted).
- 3 D2 is limited to less than 3% Cr.
- 4 When welding Group A1, A2 or B material to Group D2 or D3, the postweld heat treatment temperature shall not exceed 700°C.

TABLE 5.3
PARENT MATERIAL GROUPING

AS material group (Note 3)	Material type	Nominal composition	R_m MPa	Form	Typical specification (grade and alloy or UNS number)	ASME BPVC-IX classification			ISO/TR 15608
						Welding		Brazing	
						P. No.	Group No.	P. No.	Group No.
Ferrous materials (Fe ≥ 50%)									
Carbon and carbon manganese steel									
A1	Carbon and carbon manganese low strength steel C ≤ 0.30 Si ≤ 0.60 Mn ≤ 1.7 $R_m \leq 460$	C-Mn	430	PS	AS 1548 (7-430, PT430)	1	1	101	1.1
		C-Mn-Si	460	PS	AS 1548 (7-460, PT460)	1	1	101	1.1
		C	4	PS	AS/NZS 1594 (HU300)	1	1	101	1.1
		C-Mn-Si	415	PT	ASTM A106B (K03006)	1	1	101	—
		C	415	PS	ASTM A515-60 (K02401)	1	1	101	1.1
		C-Si	450	PS	ASTM A515-65 (K02800)	1	1	101	1.1
		C-Mn-Si	460	PS	EN 10028-2 (P295 GH4 1.04)	1	1	101	1.2
		C	390	PS	EN 10028-3 (P275N) (K0486)	1	1	101	1.1
		C-Mn	460	PS	GB 6654 16MnR	1	1	101	—
		C-Mn-Si	410	PS	IS 2062 E250 A,B,C	1	1	101	1.3
		C-Mn	310–455	PT	API 5L A,B,X42,X52	1	1	101	1.1
		C	430	PS	AS/NZS 1594 (HA350)	1	1	101	1.2
		C-Mn	430	PS	AS/NZS 1594 (HW350)	1	1	101	1.2
		C	410	PS	AS/NZS 3678 (250)	1	1	101	1
		C-Mn	430	PS	AS/NZS 3678 (300)	1	1	101	—
		C-Mn	430	PS	AS/NZS 3678 (350)	1	1	101	—
		C	330	PT	ASTM A53 A (K02504)	1	1	101	11.1
		C	415	PT	ASTM A53 B (K03005)	1	1	101	11.1
		C	330	PT	ASTM A106 A (K02501)	1	1	101	11.1

(continued)

TABLE 5.3 (continued)

AS material group (Note 3)	Material type	Nominal composition	R_m MPa	Form	Typical specification (grade and alloy or UNS number)	ASME BPVC-IX classification			ISO/TR 15608
						Welding		Brazing	
						P. No.	Group No.	P. No.	Group No.
A2	Carbon and carbon manganese Medium strength steel $R_m \leq 540$	C-Mn-Si	490	PS	AS 1548 (5-490, 7-490, PT 490)	1	2	101	11.1
		C-Mn-Si	485	PT	ASTM A106C (K03501)	1	2	101	11.1
		C-Mn-Si	485	PS	ASTM A516-70	1	2	101	11.1
		C-Mn-Si	485	PS	ASTM A516-70	1	2	101	11.1
		C-Mn-Si	510	PS	EN 10028-2 (P3554 H 1.0478)	1	2	101	1.2
		C-Mn-Si	540	PS	AS 1548 (PT540)	1	2	101	1.2
		C-Mn	460	PS	AS/NZS 1594 (HA400)	1	2	101	—
		C-Mn	460	PS	AS/NZS 1594 (XF 400)	1	2	101	—
		C-Mn	460	PS	AS/NZS 3678 (406)	1	2	101	—
		C-Mn	510	PS	AS/NZS 3678 (450)	1	2	101	—
		C-Mn	490	PT	API 5L X56	1	2	101	1.3
		C-Mn	515	PT	API 5L X60	1	2	101	1.3
		C-Mn	530	PT	API 5L X65	1	2	101	1.3
		C-Mn-Si	485	PS	JIS C 3118 (SCV 480)	1	2	101	1.2
A3	Carbon and carbon manganese high yield strength steel $R_m > 540$ $R_e > 360$	C-Mn	570	PS	AS/NZS 1594 (XF 500)	1	3	101	1.3
		C-Mn	565	PT	API 5L X70	1	3	101	1.3
A4	Carbon and carbon manganese steel (quenched and tempered) or equivalent	C-Mn-Si-V-Nb	450	PS	ASTM A656 T3-80	1	4	101	—
		C-Mn-Si-V-Nb	550	PS	ASTM A656 T4-80	1	4	101	—
		C-Mn-Si	620	PS	ASTM A724 A (K11831)	1	4	101	1.3
		C-Mn-Si	655	PS	ASTM A724 B (K12031)	1	4	101	1.3

(continued)

TABLE 5.3 (continued)

AS material group (Note 3)	Material type	Nominal composition	R_m MPa	Form	Typical specification (grade and alloy or UNS number)	ASME BPVC-IX classification			ISO/TR 15608
						Welding		Brazing	
						P. No.	Group No.	P. No.	Group No.
		C-Mn-Si	620	PS	ASTM A7 C (K12037)	1	4	101	1.3
		C-Mn	620	PT	API 5L X80	1	4	101	1.3
		C-Mn-(B)	490	PS	JIS-G3115 SPV 490	1	4	101	1.3
Low alloy steel									
B	Low alloy steel (alloy <1½)	Mn-0.5Mo	550	PS	ASTM A533 A1 (K1251)	3	3	101	3.1
		Mn-0.5Mo	620	PS	ASTM A533 A2 (K1251)	3	3	101	3.1
		Mn-0.5Mo-0.25 Ni	550	PS	ASTM A533 B1 (K12529)	3	3	101	3.1
		Mn-0.5Mo-0.25 Ni	620	PS	ASTM A533 B2 (K12529)	3	3	101	3.1
		C-0.5Mo	450	PS	ASTM A204 A (K11820)	3	1	101	1.1
		C-0.5Mo	485	PS	ASTM A204 B (K12020)	3	2	101	1.1
		C-0.5Mo	515	PS	ASTM A204 C (K12320)	3	2	101	1.1
		0.5C-0.5Mo	380	PS	ASTM A387 2-1 (K12143)	3	1	101	4.2
		0.5C-0.5Mo	485	PS	ASTM A387 2-2 (K12143)	3	2	101	4.2
C	Low alloy steel (1½ ≥ total alloy <3)	1Cr-0.5Mo	300	PS	ASTM A387 12-1 (K11757)	4	1	100	5.1
			450	PS	ASTM A387 12-2 (K11757)	4	1	102	5.1
		1.25Cr-0.5Mo-Sr	415	PS	ASTM A387 11-1 (K11789)	4	1	102	5.1
			515	PS	ASTM A387 11-2 (K11789)	4	1	102	5.1
D1	Low alloy steel [Vanadium type] (V ≤ 0.35, Cr ≤ 7)	3Cr-1Mo-V-Ti-B	585	F	ASTM A182 (K31830)	5C	1	102	6.2
		2.25Cr-1Mo-V	585	PS	ASTM A832 (K31835)	5C	1	102	6.2
		3Cr-1Mo-25V-Nb-Ca	585	F	ASTM A182	5C	1	102	6.2

(continued)

TABLE 5.3 (continued)

AS material group (Note 3)	Material type	Nominal composition	R_m MPa	Form	Typical specification (grade and alloy or UNS number)	ASME BPVC-IX classification			ISO/TR 15608
						Welding		Brazing	
						P. No.	Group No.	P. No.	Group No.
		Ni-Cr-Mo-V	590	PS	BS EN 10028-7, ISO 9606 (all Parts)	—	—	102	6.1
		0.5Cr-0.5Mo-0.25V	460	PT	BS EN 10216-2, BS EN 10217-2	—	—	102	6.1
		3Cr-1Mo-V-Ti-B	585	F	ASTM A182 F3V (K31830)	5C	1	102	6.2
D2	Low Mo alloy steel (3 ≤ total alloy <5)	2.25Cr-1Mo	415	PS	ASTM A387 22-1 (K21590)	5A	1	102	5.2
		2.25Cr-1Mo	515	PS	ASTM A387 22-2 (K21590)	5A	1	102	5.2
		3Cr-1Mo	515	PS	ASTM A387 21-2 (K31545)	5A	1	102	5.2
D3	Cr-Mo steel Cr > 3.5	5Cr-½Mo	515	PS	ASTM A387 5-2 (K41545)	5B	1	102	5.3
		9Cr-1Mo (F9)	515		ASTM A182 F9 (K90941)	5B	1	102	5.3
D4	Alloy steel Cr >7% (Vanadium or tungsten type)	9Cr-1Mo-V (F91)	585	F	ASTM A182 (K90901)	15E	1	102	6.4
		9Cr-1Mo-V (F91)	585	PS	ASTM A387 (K91560)	15E	1	102	6.4
		9Cr-1Mo-V (T91)	585	PT	ASTM A213 (K90901)	15E	1	102	6.4
		9Cr-1Mo-V	630	PT	EN 10216-2 X10CrMoVNb9-1	15E	1	102	6.4
		9Cr-2W (P92)	620	PS	ASTM A335 (K92460)	15E	1	102	6.4
E1	Nickel steel (1.0 < Ni ≤ 3)	1.5Ni	415	F	ASTM A350 LF5-1 (K13050)	9A	1	101	9.1
		2Ni-1Cu	435	PT	ASTM A333 (K22035)	9A	1	101	9.1
		2.5Ni	450	PS	ASTM A203A (K21703)	9A	1	101	9.1
E2	Nickel steel (3 < Ni < 8)	3.5Ni	450	PS	ASTM A203D (K31718)	9B	1	101	9.3
		4.5Ni	485	C	ASTM A352 (J41500)	9C	1	101	9.3
F	8 and 9 Nickel steel	8Ni	690	S	ASTM A553-II (K71340)	11A	1	101	9.3
		9Ni	690	PS	ASTM 353 (K81340)	11A	1	101	9.3
		9Ni	690	PT	ASTM A333-8 (K81340)	11A	1	101	9.3
			690	F	ASTM A522-1 (K81340)	11A	1	101	9.3

(continued)

TABLE 5.3 (continued)

AS material group (Note 3)	Material type	Nominal composition	R_m MPa	Form	Typical specification (grade and alloy or UNS number)	ASME BPVC-IX classification			ISO/TR 15608
						Welding		Brazing	
						P. No.	Group No.	P. No.	Group No.
G1	Quenched and tempered low alloy steel ($R_m \geq 640$ $R_e > 360, \leq 750$)	Mn-0.5Mo	690	PS	ASTM A533-A3 (K12521)	11A	4	101	3.1
		Mn-0.5Mo-0.25Ni	690	PS	ASTM A533-D3 (K12529)	11A	4	102	3.1
		3.5Ni-1.75Cr-0.5Mo-V	725	F	ASTM A508-4Ni (K22315)	11A	5	102	3.1
		3Ni-1.75Cr-5Mo	725	PS	ASTM A543-B1 (K42399)	11A	5	102	3.1
		2.75Ni-1.5Cr-0.5Mo	725	PS	ASTM A543-C1	11A	5	102	3.1
G2	Quenched and tempered low alloy steel ($R_m \geq 750$)	3.5Ni-1.75Cr-5Mo	795	PS	ASTM A543-82 (K42339)	11B	10	102	3.1
		Ni-Cr-Mo-B	790	PS	AS 3597 700PV	11B	10	102	3.1
		3.5Ni-1.75Cr-5Mo	795	PS	ASTM A543B2 (K42339)	11B	10	102	3.1
		0.75Ni-0.5Cr-0.5Mo-V	760	PS	ASTM A514-F (K11576)	11B	3	101	3.1
		0.5Cr-0.25Mo-V (etc.)	760 690	PS	Other ASTM A514 grades—A, B, E, P, Q	11B	1, 2, 8, 9	101	3.1
		0.5Cr-0.25Mo-Si	795	F	ASTM A517—A (K11856)	11B	2, 3, 4, 8	102	3.1
			795 725	F	Other ASTM A517 grades—B, E, F, P	11			
High alloy steel									
H	Martensitic chromium steel (Cr ≥ 10.5)	13Cr; 13Cr-5Mo	450	PS	ASTM A240 (S41000)	6	1	102	7.2
		13Cr-4.5Ni-Mo	795	PT	ASTM A268 (S41500)	6	4	102	7.2
		15Cr	415	PT	ASTM A268 (S42900)	6	2	102	7.2
J	Ferritic high chromium steel (Cr ≥ 10.5 and <19)	12Cr (403)				7	1	102	7.1
		12Cr-1Al (405)	415	PS	ASTM A240 (S40500)	7	1	102	7.1
		12Cr-Ti (408)	380	PT	ASTM A268 (S40800)	7	1	102	7.1

(continued)

TABLE 5.3 (continued)

AS material group (Note 3)	Material type	Nominal composition	R_m MPa	Form	Typical specification (grade and alloy or UNS number)	ASME BPVC-IX classification			ISO/TR 15608
						Welding		Brazing	
						P. No.	Group No.	P. No.	Group No.
		11Cr-Ti(409)	380	PS	ASTM A240 (S40920)	7	1	102	7.1
		12Cr-1Ni(401)	455	PS	ASTM A1010 (S41000)	7	1	102	—
		13Cr(401)	450	PS	ASTM A240 (S41000)	7	1	102	7.2
		17Cr (430)	415	TS	ASTM A268 (S43000)	7	2	102	7.1
		18Cr-Ti(439)	415	T	ASTM A268 (S43035)	7	2	102	7.1
		18Cr-Ti (439)	415	PT	ASTM A731 (S43035)	7	2	102	7.1
		18Cr-2Mo	415	PT	ASTM A731 (S44400)	7	2	102	7.1
K1	Austenitic Cr-Ni steel (Cr < 19%)	17Cr-7Ni (301)	515	PS	ASTM A240 (S30100)	8	1	102	8.1
		18Cr-8Ni (302)	515	PS	ASTM A240(S30200)	8	1	102	8.1
		18Cr-8Ni (304)	515	PS	ASTM A240 (S30400)	8	1	102	8.1
		18Cr-8Ni	520	PS	EN 10028-7 (X5C-Ni-Mo17-12-2)	8	1	102	8.1
		18Cr-8Ni (304L)	485	S	ASTM A240 (S30403)	8	1	102	8.1
		18Cr-8Ni (304N)	550	S	ASTM A240 (S30451)	8	1	102	8.1
		18Cr-8Ni (304LN)	515	S	ASTM A240 (S30453)	8	1	102	8.1
		18Cr-11Ni (305)	515	PS	ASTM A240 (S30500)	8	1	102	8.1
		16Cr-12Ni-2Mo (316, 316N, 316LN)	515	PS	ASTM A240 (S31600)	8	1	102	8.1
		18Cr-13Ni-3Mo (317)	515	PS	ASTM A240 (S31700)	8	1	102	8.1
		18Cr-10Ni-Ti (321)	515	PS	ASTM A240 (S32100)	8	1	102	8.1
		18Cr-10Ni-Nb (347)	515	PS	ASTM A240 (S34700)	8	1	102	8.1
		18Cr-10Ni-Nb (348)	515	PS	ASTM A240 (S34800)	8	1	102	8.1
		18Cr-10Ni-2Si (XM-15)	515	PS	ASTM A240 (S38100)	8	1	102	8.1

(continued)

TABLE 5.3 (continued)

AS material group (Note 3)	Material type	Nominal composition	R_m MPa	Form	Typical specification (grade and alloy or UNS number)	ASME BPVC-IX classification			ISO/TR 15608
						Welding		Brazing	
						P. No.	Group No.	P. No.	Group No.
K2	Austenitic Cr-Ni steel (Cr $\geq$ 19)	25Cr-20Ni (308)			ASTM A308	8	2	102	8.2
		23Cr-12Ni (309)			ASTM A309 (also with Nb)	8	2	102	8.2
		(also with Nb)			ASTM A310 (also with Nb)	8	2	102	8.2
		25Cr-20Ni (310 S)	515	PS	ASTM A240 (S31008)	8	2	102	8.2
		25Cr-20Ni (310 H)	515	PS	ASTM A240 (S31009)	8	2	102	8.2
		25Cr-20Ni-Nb (310 Nb)	515	PS	ASTM A240 (S31040)	8	2	102	8.2
		25Cr-22Ni-2Mo-N	550	PS	ASTM A240 (S31050)	8	2	102	8.2
K3	Austenitic Cr-Ni-Mn steel (4 $\leq$ Mn $\leq$ 12)	20Ni-8Cr (331)	550	F	ASTM A182 F10 (S33100)	8	2	102	8.1
		17Cr-4Ni-6Mn (201)	515	PS	ASTM A240 (S20100)	8	3	102	8.3
		18Cr-5Ni-9Mn	620	PS	ASTM A240 (S20200)	8	3	102	8.3
		22Cr-13Ni-5Mn (209)	690	PS	ASTM A240 (S20910)	8	3	102	8.3
		19Cr-8Mn-6Ni-Mo-N (216)	620	PS	ASTM A240 (S21600)	8	3	102	8.3
		21Cr-6Ni-9Mn (219)	620	PT	ASTM A321 (S21900)	8	3	102	8.3
K4	Austenitic Cr-Ni-Mo steel (Mo $\geq$ 4%) (Alloy $\geq$ 38%)	18Cr-3Ni-12Mn (240)	690	PT	ASTM A249 (S24000)	8	3	102	8.3
		20Cr-18Ni-6Mo (312)	650	PS	ASTM A240 (S31254)	8	4	102	8.2
		19Cr-15Ni-4Mo (317)	515	PS	ASTM A240 (S31725)	8	4	102	8.1
		19Cr-15.5Ni-4Mo (317)	515	PS	ASTM A240 (S31726)	8	4	102	8.1
L	High Cr steel (Ferritic stainless) (Cr $\geq$ 20; Ni $<$ 5)	24Cr-17Ni-6Mn-4.5Mo-N	795	PS	ASTM A240 (S34565)	8	4	102	8.3
		27Cr	450	PT	ASTM A268 TP446-2(S44600)	10I	1	102	7.1
		27Cr-1Mo-Ti	470	PS	ASTM A240 XM-33 (S44626)	10I	1	102	7.1
		27Cr-1Mo	450	PS	ASTM A240 XM-27 (S44627)	10I	1	102	7.1

(continued)

TABLE 5.3 (continued)

AS material group (Note 3)	Material type	Nominal composition	R_m MPa	Form	Typical specification (grade and alloy or UNS number)	ASME BPVC-IX classification			ISO/TR 15608
						Welding		Brazing	
						P. No.	Group No.	P. No.	Group No.
		25Cr-4Ni-4Mo-Ti	620	PS	ASTM A268 (S44635)	10I	1	102	7.1
		29Cr-4Mo	550	PS	ASTM A240 (S44700)	10I	1	102	7.1
		26Cr-3Ni-3Mo	585	PT	ASTM A268 (S44660)	10K	1	102	7.1
		29Cr-4Mo-2Ni	550	PT	ASTM A731 (S44800)	10K	1	102	7.1
M	Austenitic-ferritic Cr-Ni steel (Duplex) (Cr ≤ 24)	18Cr-5Ni-3Mo-N	625	PT	ASTM A789 315 (S31500)	10H	1	102	10.1
		21Cr-5Mo-1.5Ni-Cu-N	650	PS	ASTM A240 320 (S32001)	10H	1	102	10.1
		22Cr-5Ni-3Mo-N	655	PS	ASTM A240 2205 (S32205)	10H	1	102	10.1
		22Cr-4Ni-3Mo-N	620	PS	ASTM A240 318 (S31803)	10H	1	102	10.1
		23Cr-4Ni-Mo-Cu-N	690	PT	ASTM A789 323 (S32304)	10H	1	102	10.1
	Cr > 24	25Cr-6Ni-Mo-N	690	PS	ASTM A240 312 (S31200)	10H	1	102	10.2
		25Cr-5Ni-3Mo-2Cu	760	PS	ASTM A240 325 (S32550)	10H	1	102	10.2
		25Cr-8Ni-3Mo-W-Cu-N	745	PS	ASTM A240 327 (S32760)	10H	1	102	10.2
		26Cr-4Ni-Mo	620	PS	ASTM A240 329 (S32900)	10H	1	102	10.2
		25Cr-7Ni-3Mo-2W-Cu-N	800	PT	ASTM A790 392 (S39274)	10H	1	102	10.2
Non-ferrous materials									
Aluminium and aluminium alloys									
21	Al and its alloys Alloy ≤1 ($R_m < 150$)	99.6Al (1060)	55	PS	AS/NZS 1734, ASTM B209 (A91060)	21	—	104	21
		99Al-Cu (1100)	76	PS	ASTM B209 (A91100)	21	—	104	22.1
		Al-Mn-Cu (3003)	97	PS	ASTM B209 (A93003)	21	—	104	22.1
		Al-1.5Mg	125	PS	ASTM B209 (A95050)	21	—	104	22.1

(continued)

TABLE 5.3 (continued)

AS material group (Note 3)	Material type	Nominal composition	R_m MPa	Form	Typical specification (grade and alloy or UNS number)	ASME BPVC-IX classification			ISO/TR 15608
						Welding		Brazing	
						P. No.	Group No.	P. No.	Group No.
22	Al alloys (Mg ≤ 3.5) (5000 series) ($R_m < 230$) (non-heat treatable)	Al-Mn-Mg (3004)	150	PS	ASTM B209 (A93004)	22	—	104	22.2
		Al-2.5Mg (5050)	170	PT	ASTM B209 (A95052)	22	—	105	22.3
		Al-2.5Mg (5052)	170	PS	AS/NZS 1867, ASTM B210 (A95052)	22	—	105	22.3
		Al-2.7Mg-Mn (5454)	215	PS	ASTM B209 (A95454)	22	—	105	22.3
		Al-3.5Mg (5154)	205	PS	ASTM B209 (A95154)	22	—	105	22.4
23	Al-Mg-Si alloys (heat treatable)	Al-Mg-Si-Cu (6061)	165	PS	ASTM B209 (A96061)	23	—	105	23.1
		Al-Mg-Si (6063)	115	PT	ASTM B210 (A96063)	23	—	105	23.1
25	Al-Mg alloys (Mg > 3.5) ($R_m \geq 230$) (non-heat treatable)	Al-4.4Mg-Mn (5083)	275	PS	ASTM A5058	25	—	105	22.4
		Al-4Mg-Mn	235	PS	ASTM A5086	25	—	105	22.4
		Al-5.1Mg-Mn	290	PS	ASTM A5456	25	—	105	22.1
26	Al-Si castings (Si > 5, Cu ≤ 1)	Al-Si	170	C	ASTM B26 T71 (A03560)	26	—	104	24.1
		Al-10Si-Mg	150	C	EN 1706 (AC 43000)	26	—	104	24.1
Copper and copper alloys									
31	Copper (min 99.0Cu)	99.9Cu	205	PS	ASTM B152 (C11000)	31	—	107	31
		99.95Cu-P	205	PT	ASTM B68 (C10200)	31	—	107	31
		99.95Cu + Ag	205	PS	ASTM B152 (C10400)	31	—	107	31
		99.9Cu-P	205	PT	ASTM B68 (C12000)	31	—	107	31
		99.4Cu-As-P	205	PS	ASTM B152 (C14200)	31	—	107	31
32	Cu-Zn alloys	60Cu-39Zn-Pb	275	PS	ASTM B71 (C36500)	32	—	107	32.2
		60Cu-39Zn-Pb	345	PS	ASTM B171 (C36400)	32	—	107	32.2
		85Cu-15Zn	275	PT	ASTM B395 (C23000)	32	—	107	32.2

(continued)

TABLE 5.3 (continued)

AS material group (Note 3)	Material type	Nominal composition	R_m MPa	Form	Typical specification (grade and alloy or UNS number)	ASME BPVC-IX classification		ISO/TR 15608	
						Welding		Brazing	Group No.
						P. No.	Group No.	P. No.	
		71Cu-28Zn-1Sn-0.6As	310	PS	ASTM B171 (C44300)	32	—	107	32.2
		78Cu-20Zn-2Al	345	PT	ASTM B171 (C68700)	32	—	107	32.2
		60Cu-40Zn	345	PT	ASTM B111 (C28000)	32	—	107	31
		71Cu-28Zn-1Sn-0.6Sb	310	PS	ASTM B171 (C44400)	32	—	107	32.2
		71Cu-28Zn-1Sn-0.06P	310	PS	ASTM B171 (C44500)	32	—	107	32.2
		76Cu-20Zn-2Al	345	PT	ASTM B543 (C68700)	32	—	107	32.2
33	Cu-Si alloys	97Cu-3Si	345	PS	ASTM B96 (C65500)	33	—	107	37
34	Cu-Ni alloys	90Cu-10Ni (<64 mm)	275	PS	ASTM B171 (C70600)	34	—	107	34
		80Cu-20Ni	310	PT	ASTM B359 (C71000)	34	—	109	34
		70Cu-30Ni (<64 mm)	315	PS	ASTM B171 (C71500)	34	—	107	34
35	Aluminium bronze alloys (>5Al)	88Cu-9Al-3Fe	450	C	ASTM B271 (C95200)	35	—	108	35
		90Cu-7Al-3Fe	485	PS	ASTM B171 (C61400)	35	—	108	35
		95Cu-5Al	345	PT	ASTM B111 (C60800)	35	—	108	35
		81Cu-10Al-5Ni-3Fe	550	PS	ASTM B171 (C63000)	—	—	—	—
36	Cu-Ni-Zn alloys					Note 2	—	—	36
37	Copper alloys, low-alloyed (<5% other elements not in 31 to 36)					Note 2	—	—	37
38	Other copper alloys (≥5% other elements not in 31 to 36)					Note 2	—	—	38

(continued)

TABLE 5.3 (continued)

AS material group (Note 3)	Material type	Nominal composition	R_m MPa	Form	Typical specification (grade and alloy or UNS number)	ASME BPVC-IX classification			ISO/TR 15608
						Welding		Brazing	
						P. No.	Group No.	P. No.	Group No.
Nickel and nickel alloys									
41	Nickel and low carbon nickel	99.0Ni (200)	380	PS	ASTM B162 (N02200)	41	—	110	41
		99.0Ni-low C (201)	345	PS	ASTM B162 (N02201)	41	—	110	41
42	Ni-Cu alloy (Ni ≥ 45, Cu ≥ 10)	67Ni-30Cu (400)	485	PS	ASTM B127 (N04400)	42	—	110	42
		67N-30Cu	485	PT	ASTM B165, B168 (N04400)	42	—	110	42
43	Ni-Cr alloy (Ni > 45)	72Ni-15Cr-8Fe (600)	550	PP	ASTM B168 (N06600)	43	—	111	43
		58Ni-29Cr-9Fe	585	PT	ASTM B163 (N06690)	43	—	111	43
		55Ni-21Cr-13Mo	690	PS	ASTM B575 (N06622)	43	—	111	44
44	Ni-Mo alloy (Ni ≥ 45, Mo ≤ 32)	65Ni-28Mo-2Fe	795	PS	ASTM B333 (N10601)	44	—	112	44
		62Ni-25Mo-8Cr-2Fe	725	PS	ASTM B434 (N10242)	44	—	112	44
		65Ni-28Mo-5Fe	690	PT	ASTM B622 (N10001)	44	—	112	44
		65Ni-28Mo-2Fe	760	PT	ASTM B622 (N10065)	44	—	112	44
		66Ni-28Mo-3Fe-1.3Cr-0.25Al	760	PS	ASTM B333 (N10629)	44	—	112	44
		65Ni-29.5Mo-2Fe-23Cr	760	PS	ASTM B333 (N10675)	44	—	112	44
		70Ni-16Mo-7Cr-5Fe	690	PS	ASTM B434 (N10003)	44	—	112	44
45	Ni-Fe-Cr alloy (Ni > 20)	25Ni-20Cr-6Mo-Co-N	650	PS	ASTM B625 (N08926)	45	—	111	8.2
		25Ni-47Fe-21Cr-5Mo	550	PS	ASTM B599 (N08100)	45	—	111	8.2
		35Ni-35Fe-20Cr-Nb	550	PT	ASTM B729 (N08020)	45	—	111	45
		44Fe-25Ni-21Cr-Mo	490	PT	ASTM B677 (N08904)	45	—	111	8.2
		27Ni-22Cr-7Mo-Co	770	PS	ASTM A240 (S31277)	45	—	111	8.2
		42Ni-21.5Cr-3Mo-2.5Co	585	PS	ASTM B424 (N08825)	45	—	111	45

(continued)

TABLE 5.3 (continued)

AS material group (Note 3)	Material type	Nominal composition	R_m MPa	Form	Typical specification (grade and alloy or UNS number)	ASME BPVC-IX classification			ISO/TR 15608
						Welding		Brazing	
						P. No.	Group No.	P. No.	Group No.
		33Ni-42Fe-21Cr	450	PT	ASTM B163 (N08800)	45	—	111	45
		32Ni-45Fe-20.5Cr-Ti	585	PT	ASTM B163 (N08800)	45	—	111	45
		42Ni-21.5Cr-3Mo-2.5Cu	585	PS	ASTM B424 (N08825)	45	—	111	45
46	Ni-Cr-Si alloy (Ni > 45)	35Ni-19Cr-1.25Si	485	PS	ASTM B536 (N08330)	46	—	111	45
		37Ni-30C-28Cr-2.7Si	620	PS	ASTM B435 (N12160)	46	—	111	45
		46Ni-27Cr-23Fe-2.8Si	620	B	ASTM B166 (N06045)	46	—	111	45
		37Ni-30C-28Cr-2.7Si	620	PT	ASTM B622 (N12160)	46	—	111	45
47	Ni-Fe-Cr-Cu alloy (Ni > 45)	—	—	—	—	Note 2	—	—	47
48	Ni-Fe-Co-Cr-Mo-Cu alloy (25 ≤ Ni ≤ 45), (Fe ≥ 20)	—	—	—	—	Note 2	—	—	48
Titanium and titanium alloys									
51	Unalloyed and alloyed Ti ($R_m \leq 420$ MPa)	Ti	240	F	ASTM B381 (R50250)	51	—	115	51
		Ti (1)	240	PS	ASTM B265-1 (R50250)	51	—	115	51
		Ti (2)	345	PS	ASTM B265-2 (R50400)	51	—	115	51
		Ti (2H)	400	PS	ASTM B265-2H (R50400)	51	—	115	51
		Ti-Ru	345	PT	ASTM B338-26 (R52404)	51	—	115	51
		Ti-Pd	345	PT	ASTM B861-7 (R52400)	51	—	115	51
52	Ti alpha alloys $R_m > 420$ MPa	Ti-0.3Mo-0.8Ni (12)	485	PT	ASTM B338-12 (R53400)	52	—	115	52
		Ti (3)	450	PT	ASTM B338-3 (R50550)	52	—	115	52
		Ti (3)	450	PS	ASTM B265-3 (R50550)	52	—	115	52
		Ti (12)	485	PS	ASTM B265-12 (R53400)	52	—	115	52

(continued)

TABLE 5.3 (continued)

AS material group (Note 3)	Material type	Nominal composition	R_m MPa	Form	Typical specification (grade and alloy or UNS number)	ASME BPVC-IX classification			ISO/TR 15608
						Welding		Brazing	
						P. No.	Group No.	P. No.	Group No.
53	Ti alpha-beta alloys	Ti-3Al-2.5V (9)	620	PS	ASTM B265-9 (R56320)	53	—	115	53
		Ti-3Al-2.5V-0.1Ru (28)	620	PT	ASTM B861-28 (R56323)	53	—	115	53
		Ti-3Al-6V-2Sn (9)	620	PT	ASTM B862- 9 (R56320)	53	—	115	53
		Ti-3Al-2.5V-0.1Ru (28)	620	PT	ASTM B862-28 (R56323)	53	—	115	53
54	Ti near-beta and beta-alloys	Ti-10V-2Fe-3Al and higher alloys			—	Note 2	—	—	54

Zirconium and zirconium alloys

61	Unalloyed Zr	99.2Zr (702)	380	PS	ASTM B651-702 (R60702)	61	—	117	61
			380	F	ASTM B493 (R60702)	61	—	117	61
			380	T	ASTM B523 (R60702)	61	—	117	61
62	Alloyed Zr	95.5Zr-2.5Nb (705)	550	PS	ASTM B551-705 (R60705)	62	—	117	62
			485	F	ASTM B493-705 (R60705)	62	—	117	62
			550	T	ASTM B523-705 (R60705)	62	—	117	62

Cast irons

NOTE: Not normally welded to PE.

71	Grey cast irons with R_m or HB	—	—	—	AS 1830, ISO 185 (JL/100 to JL/350)	Note 2	—	—	71
72	Spheroidal-graphite cast irons with specified mechanical properties	—	—	—	ISO/TR 15608 ISO 1831 (370-17) (400-12) (500-7)	Note 2	—	—	72
73	Malleable cast irons	White heart and black heart	—	—	AS 1832, ISO 5922	Note 2	—	—	73

(continued)

TABLE 5.3 (continued)

AS material group (Note 3)	Material type	Nominal composition	R_m MPa	Form	Typical specification (grade and alloy or UNS number)	ASME BPVC-IX classification			ISO/TR 15608
						Welding		Brazing	
						P. No.	Group No.	P. No.	Group No.
74	Austempered ductile cast irons	—	—	—	—	Note 2	—	—	74
75	Austenitic cast irons	—	—	—	—	Note 2	—	—	75
CI 76	Cast irons excepting 71–75	—	—	—	—	Note 2	—	—	76

LEGEND: R_m = specified minimum tensile strength R_e = 0.2% proof strength

A = % elongation

 C_v = Charpy V

HB = Hardness Brinell

B = bar or section

C = casting

F = forging

PS = plate, sheet or strip

PT = pipe or tube

NOTES:

- 1 This Table lists material groups according to composition and lists representative standards, primarily plate and pipe and R_m values only for the thinnest plate when R_m varies with the thickness.
- 2 ISO/TR 15608 for these alloys is not adopted in ASME BPVC-IX.
- 3 Where reference is made only to the group letter, all groups with the letter are referenced unless noted.
- 4 Document titles for the typical specifications may not appear in the referenced documents list. If this information is required please refer to the website of the relevant Standards organization.

TABLE 5.4
RANGE OF PARENT MATERIAL
AND WELD DEPOSIT THICKNESS QUALIFIED

Item	Welding process	Range of parent material thickness qualified (Notes 1 and 2)
1	Gas welding	$\leq t$
2	Single-run or multi-run welding where any run is greater than 13 mm throat (not applicable to GTAW)	$\leq 1.1t$
3	Gas metal-arc welding and flux cored arc welding both with short circuiting arc transfer with $t \leq 13$ mm	$\leq 1.1t$
4	Except for above Items 2 and 3, single or multi-run manual metal-arc, submerged arc, gas tungsten-arc, gas metal-arc and flux cored-arc welding	t to $2t$ for $t < 1.5$ mm 1.5 mm to $2t$ for $t \leq 10$ mm 5 mm to $2t$ for $t > 10$ mm < 40 mm 5 mm to 200 mm for $t \geq 40$ mm and ≤ 150 mm 5 mm to $1.33t$ for $t > 150$ mm (Note 3)
5	Electroslag welding	$\leq 1.1t$

NOTES:

- 1 t = thickness of test plate or pipe.
- 2 Pre-heat shall comply with Note 3 to Table 5.1.
- 3 Where impact tests are required, the minimum thickness qualified is—
 - (a) $0.5t$ when the test plate thickness (t) < 16 mm; and
 - (b) 15 mm when test plate thickness (t) $\geq$ 16 mm.
- 4 The maximum weld deposit throat thickness of each run qualified is—
 - (a) $2t_r$ when $t_r < 20$ mm; and
 - (b) the maximum parent material thickness qualified, when $t_r \geq 20$ mm,
where
 t_r = maximum throat thickness of any run in the test weld.

TABLE 5.5
FILLER METAL GROUP CLASSIFICATION

F number	Welding process	Welding consumable description (see Notes 1 and 2)	Australian Standard (see Note 3)	ASME BPVC-IIC	
				Spec. no.	Classification
Ferrous materials					
F1	MMAW	High iron powder or iron oxide electrode for carbon and carbon manganese and low alloy steels	AS/NZS 4855	SFA 5.1 and 5.5	EXX20, EXX22, EXX24, EXX27, EXX28
F2	MMAW	High titania (rutile) electrode for carbon and carbon manganese and low alloy steels	AS/NZS 4855	SFA 5.1 and 5.5	EXX12, EXX13, EXX14, EXX19
F3	MMAW	High cellulose electrode for carbon and carbon manganese and low alloy steels	AS/NZS 4855	SFA 5.1 and 5.5	EXX10, EXX11
F4	MMAW	Hydrogen controlled basic electrode for carbon and carbon manganese and low alloy steels	AS/NZS 4855	SFA 5.1 and 5.5	EXX15, EXX16, EXX18, EXX48
	MMAW	Hydrogen controlled basic electrode for high chromium other than austenitic and duplex steels	—	SFA 5.4	EXX15, EXX16, EXX17
F5	MMAW	Hydrogen controlled basic electrode for high alloy austenitic and duplex steels	—	SFA 5.4	EXX15, EXX16, EXX17
F6	Oxy acetylene welding	Filler metal rods for carbon and low alloy steels	AS/NZS 1167.2	SFA 5.2	RX
	SAW	Electrodes for carbon and carbon manganese steels	AS/NZS ISO 14171 AS/NZS ISO 14174	SFA 5.17	FXX-EXX
	SAW	Electrodes for low alloy steels	AS/NZS ISO 14174	SFA 5.23	FX-EXXX-X
	SAW	Electrodes for high alloy austenitic steels	—	SFA 5.9	ERXX
	GTAW GMAW	Electrodes for high alloy austenitic steels	AS/NZS 1167.2 ISO 14343	SFA 5.9	ERXX
	GTAW GMAW	Electrodes for carbon and carbon manganese steels	AS/NZS 1167.2 AS/NZS 14341 AS/NZS 21952 AS/NZS 16834	SFA 5.18	ERXXS-X
	GTAW GMAW	Electrodes for low alloy steels	AS/NZS 1167.2 AS/NZS 14341 AS/NZS 21952 AS/NZS 16834	SFA 5.28	ERXXX-X ERXXX-X
	FCAW	Electrodes for carbon and carbon manganese steels	AS/NZS ISO 17632 AS/NZS ISO 17634 AS/NZS ISO 18276 (see Note 4)	SFA 5.20	EXXT-X
	FCAW	Electrodes for low alloy steels	—	SFA 5.29	EXXTX-X
	FCAW	Electrodes for high alloy steels	—	SFA 5.22	EXXXT-X

(continued)

TABLE 5.5 (continued)

F number	Welding process	Welding consumable description (see Notes 1 and 2)	Australian Standard (see Note 3)	ASME BPVC-IIC	
				Spec. no.	Classification
Aluminium alloys					
F21	GTAW GMAW	Aluminium welding rod (99% aluminium)	AS/NZS 1167.2 AS/NZS ISO 18273	SFA 5.10	ER 1100
F22	GTAW GMAW	Aluminium alloy welding rod (magnesium chromium alloy)	AS/NZS 1167.2 AS/NZS ISO 18273	SFA 5.10	ER 5183 ER 5356 ER 5554 ER 5556 ER 5654
F23	GTAW GMAW	Aluminium alloy welding rod (silicon 4.5–6%)	AS/NZS 1167.2 AS/NZS ISO 18273	SFA 5.10	ER 4043 ER 4009 ER 4047 ER 4010 ER 4145
F24	GTAW GMAW	Aluminium alloy	AS/NZS 1167.2	SFA 5.10	R 356.0
F25	GTAW GMAW	Aluminium alloy electrode and rod	—	SFA 5.10	ER 2319 R 2319
Copper and copper alloys					
F31	GTAW GMAW	Copper rod (Copper 98% minimum)	AS/NZS 1167.2	SFA 5.7	ER Cu
F32	GTAW GMAW	Copper silicon rod (silicon bronze)	AS/NZS 1167.2	SFA 5.7	ER Cu Si-A
F33	GTAW GMAW	Copper tin rod (phosphor bronze)	AS/NZS 1167.2	SFA 5.7	ER Cu Sn-A
F34	GTAW GMAW	Copper nickel rod	AS/NZS 1167.2	SFA 5.7	ER Cu Ni
F35	GW	Copper alloy rod (copper zinc)	AS/NZS 1167.2	SFA 5.27	RB Cu Zn-A RB Cu Zn-B RB Cu Zn-C RB Cu Zn-D
F36	GTAW GMAW	Copper aluminium rod (aluminium bronze)	AS/NZS 1167.2	SFA 5.7	ER Cu Al-A1 ER Cu Al-A2 ER Cu Al-A3
F37	GTAW GMAW	Copper alloy gas welding rods (copper-nickel-aluminium)	AS/NZS 1167.2	SFA 5.7	ER Cu Ni Al ER Cu Mn Ni Al
Nickel and nickel based alloys					
F41	MMAW	Nickel welding electrode (nickel 92% minimum)	—	SFA 5.11	E Ni-1
	GMAW GTAW	Nickel welding rod	AS/NZS 1167.2	SFA 5.14	ER Ni-1
F42	MMAW	Nickel copper welding electrode (monel metal)	—	SFA 5.11	E Ni Cu-7
	GMAW GTAW SAW	Nickel copper welding rod (monel metal)	AS/NZS 1167.2	SFA 5.14	ER Ni Cu-7

(continued)

TABLE 5.5 (continued)

F number	Welding process	Welding consumable description (see Notes 1 and 2)	Australian Standard (see Note 3)	ASME BPVC-IIC	
				Spec. no.	Classification
F43	MMAW	Nickel chromium iron and nickel chromium molybdenum electrode	—	SFA 5.11	E Ni Cr Fe-1 E Ni Cr Fe-2 E Ni Cr Fe-3 E Ni Cr Fe-4 E Ni Cr Mo-2 E Ni Cr Mo-3 E Ni Cr Mo-6
	GMAW GTAW SAW	Nickel chromium, nickel chromium iron and nickel chromium molybdenum welding rod	AS/NZS 1167.2	SFA 5.14	ER Ni Cr-3 ER Ni Cr Fe-5 ER Ni Cr Fe-6 ER Ni Cr Mo-2 ER Ni Cr Mo-3
F44	MMAW	Nickel molybdenum and nickel chromium molybdenum electrodes	—	SFA 5.11	E Ni Mo-1 E Ni Mo-3 E Ni Mo-7 E Ni Cr Mo-4 E Ni Cr Mo-5 E Ni Cr Mo-7
	GMAW GTAW	Nickel molybdenum and nickel chromium molybdenum welding rod	AS/NZS 1167.2	SFA 5.14	ER Ni Mo-1 ER Ni Mo-2 ER Ni Mo-7 ER Ni Cr Mo-4 ER Ni Cr Mo-5 ER Ni Cr Mo-7
F45	MMAW	Nickel chromium molybdenum electrode	—	SFA 5.11	E Ni Cr Mo-1 E Ni Cr Mo-9
	GMAW GTAW	Nickel chromium molybdenum and nickel iron chromium	AS/NZS 1167.2	SFA 5.14	ER Ni Cr Mo-1 ER Ni Fe Cr-1 ER Ni Cr Mo-8 ER Ni Cr Mo-9
F46	MMAW	Nickel chromium iron electrode	—	SFA 5.11	E Ni Cr Fe Si-1
	GMAW GTAW	Nickel chromium iron rod	—	SFA 5.14	ER Ni Cr Fe Si-1
		Nickel cobalt chromium iron welding rod	—	SFA 5.14	ER Ni Cr Fe Si-1
Titanium and titanium alloys					
F51	GTAW GMAW	Titanium alloy welding rod	—	SFA 5.16	ER Ti-1 ER Ti-2 ER Ti-3 ER Ti-4
F52	GTAW GMAW	Titanium alloy welding rod	—	SFA 5.16	ER Ti-4
F53	GTAW GMAW	Titanium alloy welding rod	—	SFA 5.16	ER Ti-9 GLEI-18 GLEI-22
F54	GTAW GMAW	Titanium alloy welding rod	—	SFA 5.16	ER Ti-12

(continued)