snowy hydro Limited renewable energy	
Snowy Technical Standards	
SHL-MEC-102	**Welding**
Subject Matter Expert *Duncan Murdoch* *Mechanical Engineer*	Version Date: 20 August 2014 *(Editorial changes made 6 November 2017)* Revision: *Original*

1. Executive Summary

This standard has been prepared to address shortcomings in SHL welding preparation, processes, qualification and testing, which have been exposed by the significant cracks that occurred at Guthega Unit 2 in October 2012.

The purpose of this standard is to ensure a consistent approach and hence a consistent standard of welding for new fabrications, crack repairs and cavitation repairs across all Snowy Hydro sites.

This standard applies to welding performed by SHL and its Contractors.

2. Scope

This specification applies to all metal fabrication and repair work, involving welding, carried out by SHL and its Contractors and Subcontractors in both workshop and site situations.

These requirements apply to all Snowy Hydro sites.

This specification prescribes weld preparation, qualification of welding procedures and personnel, workmanship and inspection requirements for welds related to the arc welding by manual metal-arc and other processes approved by SHL.

Welding shall be carried out in accordance with the requirements of the Drawings and this Specification using approved welding procedure specifications and suitable equipment.

All welding related work subcontracted shall comply with this specification.

2.1. Applicable Standards

AS/NZS 1554.1:2011	Structural Steel Welding
AS 1796	Certification of Welders and Welding Supervisors
AS/NZS 3992	Pressure Equipment – Welding and Brazing Qualification
AS 4458	Pressure Equipment – Manufacture (PWHT guidance located here)
AS 2214	Minimum technical knowledge requirements for welding supervisor

3. Definitions

AODocs	The computerised business system used by Snowy Hydro for storage of all corporate documentation
IIW	International Institute of Welding
ITP	The detailed Inspection and Test Plan(s) for the proposed work
IWE	International Welding Engineer
IWI S	International Welding Inspector Standard Level
IWS	International Welding Specialist
IWT	International Welding Technologist
MDR	Manufacturer's Data Report. The MDR details the activities performed by a manufacturer and is a technical record of those activities, the procedures and testing that relate to a fabrication. It contains the complete quality documentation which is applicable to the traceability requirements of a contract and allows the client to determine if fabrications, articles and or equipment being supplied have been manufactured in accordance with particular Codes and or Specifications.
NATA	National Association of Testing Authorities
NDT/NDE	Non Destructive Testing/Evaluation
OHSMS	Occupational Health And Safety Management System
PQR	Procedure Qualification Record
Schedule	Description/requirements of Quality Assurance Requirements, and Contractors Notifications and Submissions
SD	SHL Standard Drawings
SHL	Snowy Hydro Limited
SHL RWC SHL Responsible Welding Coordinator	The person authorised to sign for all welding matters on behalf of Snowy Hydro. The person may also nominate a Designate to sign for some or all welding matters
Specified	Described in the Contract Specification or on the Contract Drawings
TWMS	Total Welding Management System
WPS - Welding Procedure Specification	A Qualified Weld Procedure which has been tested and proven
Welding	A person who carries out one or more welding coordination tasks (as defined in

Coordinator	ISO 14731) and reports to the Responsible Welding Coordinator
WSP	Welding Service Provider – the person, organisation or contractor as defined in the Contract who will undertake the welding work (this may be SHL)
Work	Means metal fabrication and repair work, involving welding
WTIA	Welding Technology Institute of Australia

4. Technical Requirements

4.1. General

All metal fabrication and welding shall comply with the Australian Standard(s) or Code(s) of Practice (including amendments) stated in the Contract Specification, noted on the Contract Drawings, and/or in the work order/purchase order detail, and/or in the ITP.

If not otherwise stated, all welding shall conform to the latest version of AS/NZS1554.1 – Structural Steel Welding.

If not otherwise stated, all welding shall be conducted to the structural purpose category as per section 1.6 of AS/NZS1554.1-2011

If not otherwise stated, all welding of stainless steel shall conform to AS/NZS1554.6-2012 – Welding Stainless Steels for Structural Purposes.

All welding of pressure equipment shall comply with AS4458-1997 – Pressure Equipment Manufacture.

Welding procedures, both WPS and PQR shall comply with the requirements of AS 3992:1998.

All metal fabrication and welding of pipe fittings and flanges shall comply with the current edition of Snowy Hydro's Technical Standards or as specified in the Contract Specification, noted on the Contract Drawings, and/or in the work order/purchase order detail, and/or the ITP.

4.2. Quality Assurance

A welding management system shall be established for all welding works and a Responsible Welding Coordinator (RWC) appointed.

The RWC shall:

a. Be responsible for all quality assurance activities necessary to ensure that the Works comply with the specified requirements
b. Provide sufficient information, with respect to any subcontractors, to ensure their suitability for the Works
c. Establish and maintain a quality assurance system as required
d. Ensure that subcontractors' operations are in accordance with the contract quality assurance system requirements
e. Submit a Quality Plan detailing how the quality assurance requirements are to be applied to each element of the Works.

The RWC shall demonstrate that:

a. Welding coordination personnel have been nominated and have clearly defined tasks and responsibilities
b. Welders and welder operators are qualified, with records, to the welding standard specified
c. Documented weld procedure specifications are in accordance with the welding standard specified
d. Non-destructive testing personnel are qualified, with records, to the non-destructive testing standard specified.
e. Plant and equipment are maintained and in good working order to prepare, execute and deliver the contract in a safe and timely manner
f. A system is in place to control quality documentation such as weld procedure specifications, weld procedure approval record and welder approval certificate.
g. Where post weld heat treatment is required, the supplier can provide a written procedure and a record obtained during this process demonstrating conformity
h. A system is in place to control inspection and testing prior to , during and after welding
i. A system is in place to maintain calibration of all equipment that assesses the quality of the welded construction

Prior to production, the weld procedure specifications shall be prepared in accordance with the appropriate part of the welding standard specified in the contract, purchase order, or ITP.

4.3. Qualification of Procedures and Personnel

The welding procedure specification, which includes the weld preparation, welding consumables and the welding parameters, shall be qualified before welding commences.

Welding procedure specifications shall be proven and qualified, refer to Figure 1 . Both the Welding Procedure Specification and a Procedure Qualification Record (PQR) shall be submitted and reviewed by the relevant technical specialist and stored in AODocs.

A qualified WPS shows all variables. If an essential variable is changed then a new PQR needs to be qualified. Essential variables in AS/NZS 1554.1 and AS/NZS 1554.6 are given in Table 4.11(A), in AS 3992 in Table 5.1.

Testing performed to qualify the PQR shall be in accordance with the relevant standard for which the procedure is intended.

The test coupon shall be hard stamped or permanently marked with the PQR number. The test report shall indicate the unique PQR number assigned to the Welding Procedure.

On completion of welding the qualification test piece, a 100% visual examination of the completed weld shall be performed to verify compliance with the relevant Standard. The test coupon(s) shall be submitted to a National Association of Testing Authorities (NATA) approved testing laboratory for mechanical and non-destructive testing, as appropriate.

Copies of all Qualified PQR documentation shall be stored in AODocs. Included in this package should be material certificates, consumable certificates, run-sheets taken during qualification testing, NDE reports and mechanical test reports.

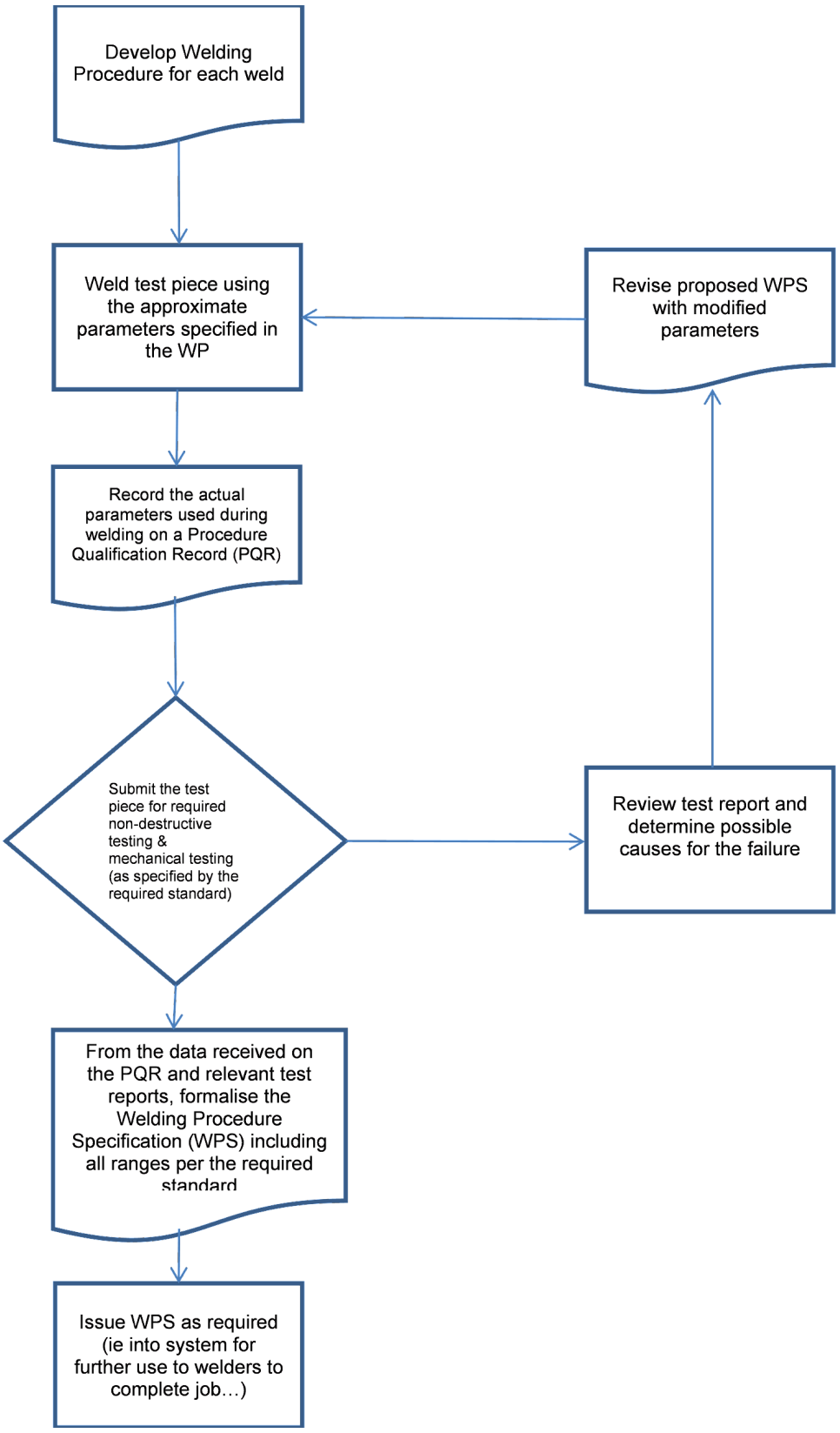

Figure 1: Weld Procedure Qualification Flowchart

Welders not already qualified for the welding process and position required by the welding procedure shall be required to demonstrate an ability to comply with the appropriate requirements of this Standard by welding a suitable test piece. . Alternatively, welders may be qualified to AS 1796 with the relevant process or AS 2980, also with the relevant process.

Each test weld shall have a minimum examination length of 300 mm. Butt welds shall preferably be examined using NDE. Alternatively, butt and fillet welds may be examined visually and by means of a macro test. The validity of each welder's qualification shall be reassessed every six months. During any previous six month period, if evidence of satisfactory welding cannot be produced, the welder shall undergo a full re-test.

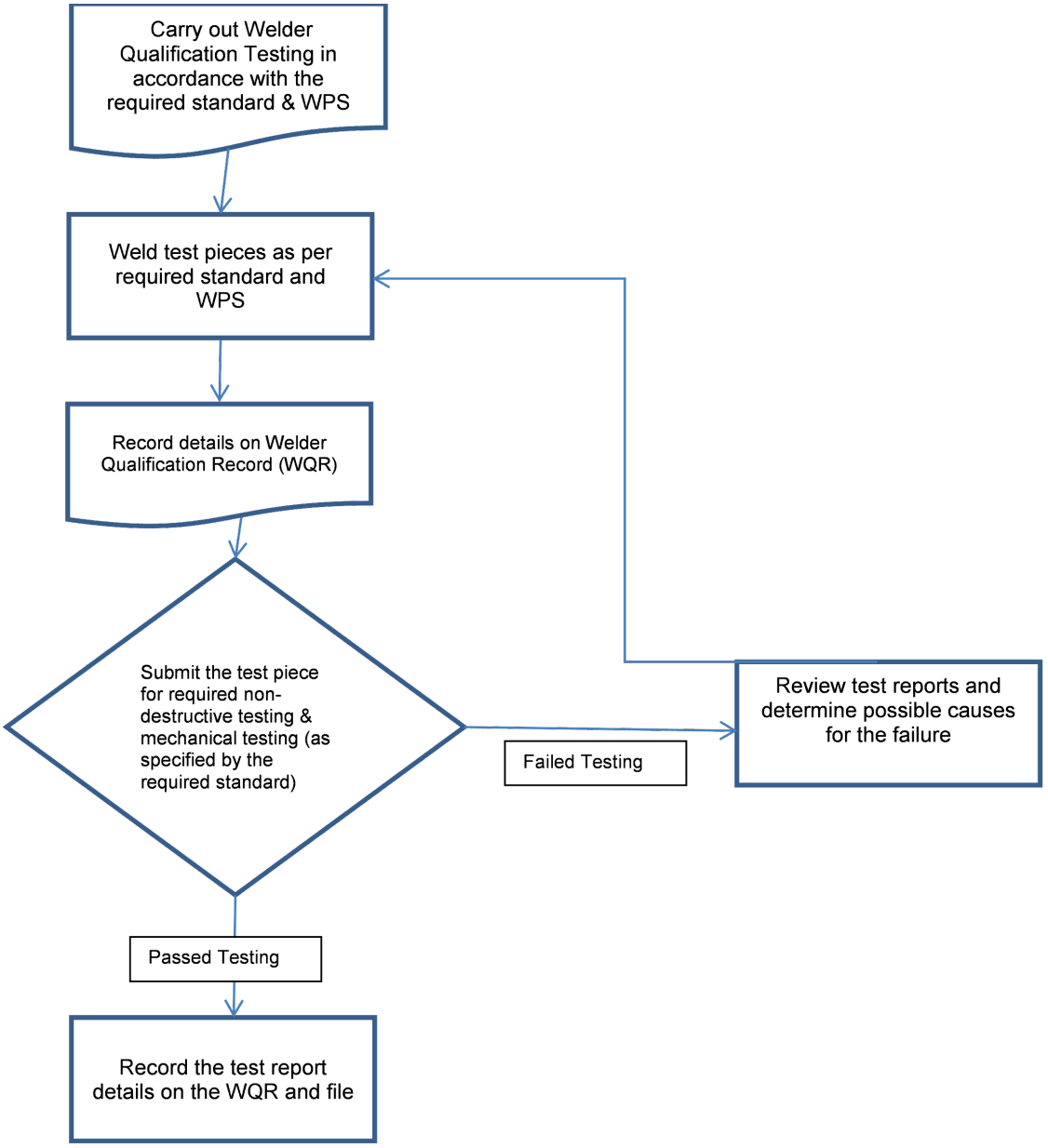

Figure 2: Welder Qualification Flowchart

4.4. Welding Procedure Information

Copies of the approved WPSs shall be available at the work site at all times.

The WPSs shall contain all of the major parameters/essential variables and at least the following:

a. A sketch of the joint design
b. Material specifications
c. Material thickness range – all parts
d. History of failures and previous repairs (for crack and cavitation repairs)
e. Method(s) of material preparation
f. Welding processes to be used
g. Voltage, amperage, and travel speed ranges for each weld pass
h. Number and sequence of runs
i. Classification of electrode/wire
j. Diameter of electrode/wire
k. Shielding gas/gas mixture/flux type/classification
l. Temperature of preheat, inter run heat and post heat applications, as applicable
m. Heat input (kJ/mm) for each weld pass
n. Welding standard and classification (eg AS/NZS 1554.1 SP, AS4041 Class 2P)
o. Run-on and run –off tabs
p. The type and extent of testing of welds to be carried out in accordance with the specified testing requirements.

4.5. Inspection and Testing

a. An inspection and test plan for all engineering work shall be prepared, and
b. the inspection and test plan shall contain the necessary elements to ensure the completed welding work complies with the specified standards and other specified requirements.

a. testing of all welds shall be carried out in accordance with the specified standards and other specified requirements, and
b. test certificates, issued by a NATA accredited laboratory, for both destructive and non-destructive testing, shall be provided.

A minimum of 10%, of all welds, shall be inspected by NDT of the type(s) specified, shall be carried out on all fabrications and repairs unless specified otherwise in the specification or ITP.

Where required by the contract specification, pressure testing shall be carried out and recorded

Where testing reveal detects or non-compliance with relevant specified standards/codes/and specifications, repair of such defects shall be done using the same welding procedure and the same testing technique as that used for the first weld. The costs of weld repair and retesting shall be borne by the contractor.

On completion of repairs, the same NDT shall be performed to confirm that the repair has been successful.

4.6. New Fabrications

Specific design requirements for welding shall be specified in the Technical Specification.

As a minimum requirement, 25% of new welds shall be subject to a non-destructive examination technique such as liquid penetrant or magnetic particle in accordance with relevant Australian Standards.

For structural steel welded in accordance with AS/NZS 1554.1, the amount of ultrasonic or radiographic testing shall be identified prior to start of work.

4.7. Crack Repairs (Turbine Runners Only)

The failure and previous repair history of the material to be repaired must be known and understood before commencing the weld repairs.

Unless the structural integrity of a turbine runner is at risk, welding of runner cracks shall not occur. Welding may cause more severe cracking. A record shall be kept documenting the location and length of cracks as best as possible.

Welding of runner cracks will only be performed once the crack is deemed (by Asset Specialist) to have reached a critical length where failure is imminent.

Surface and edges to be welded shall be uniform and free from tears, cracks and other defects. All surfaces to be welded and adjacent to weld shall be free from scale, slag, rust, grease, paint and other foreign matter.

If the completed weld is to be subject to a NDT inspection, the surface of the weld preparation area shall be given a similar NDT inspection prior to welding.

Preheat requirements are highly dependent on the extent of carbon equivalent, thickness and area being repaired, heat input during welding and welding material. The preheat temperatures for structural steel can be estimated from Appendix B – Preheat Temperature For pressure equipment, preheat can be obtained from Table 10.1 of AS4458

Each welding run must be thoroughly cleaned to remove slag and spatter before proceeding with the next run, using the process specified in the WPS.

Run-on/run-of tabs are to be used to ensure a consistent weld at the edge of the repaired area.

All final finished surfaces shall subject to a thorough 100% visual inspection.

100% Dye Penetrant examination shall also be performed.

Post Weld Heat Treatment is only required under very specific conditions. Refer to AS 4458 and WTIA Technical note 16 for further details.

4.8. Cavitation Repairs

Prior to cavitation repair, dimensional checks of the component shall be made to serve as a basis for the detection of distortion.

For turbine runner vane repairs, if extensive welding is to be undertaken, braces or strong-backs are to be used on the pressure side of the opposite vane to minimise distortion.

Surface preparation shall be by grinding or chipping to sound metal and shall extend to 5-15 mm beyond the cavitation affected zone. Chipping is not recommended on austenitic stainless steels

If the welding consumable is different to base metal, the edge of the preparation should be square cut to avoid a feather edge at the joint.

The prepared area shall, at a minimum, be visually inspected for defects. Magnetic particle inspection on carbon and martensitic steels or dye penetrant on austenitic steels is recommended.

Preheat requirements are highly dependent on the extent of carbon equivalent, thickness and area being repaired, heat input during welding and welding material. Preheat shall be measure and maintained to 50mm beyond the weld repair area. The preheat temperatures can be estimated from Appendix B – Preheat Temperature

No more than 3mm of weld material shall be applied per pass to minimise distortion and residual stress

The maximum interpass temperature shall not exceed that measured during PQR testing.

Weld shall be applied using a cross pattern or temper bead technique. Cross pattern shall be arranged such that the final pass is in the direction of water flow.

Post Weld Heat Treatment is only required in very specific conditions. Refer to AS 4458 and WTIA Technical note 16 for further details.

Surfaces shall be ground to their original profile. Recommended upper limit surface finishes are defined in Appendix C – Surface Finish

All final finished surfaces shall be subject to a thorough 100% visual inspection.

100% dye penetrant examination shall also be conducted.

Final dimensional checks shall be undertaken to determine the occurrence of distortion. A tolerance of 1% is acceptable.

5. References

- AS/NZS 1554.1:2011 Structural Steel Welding
- AS 1796 Certification of Welders and Welding Supervisors
- AS/NZS 3992 Pressure Equipment – Welding and Brazing Qualification
- AS 4458 Pressure Equipment – Manufacture (PWHT guidance located here)
- AS 2214 Minimum technical knowledge requirements for welding supervisor
- WTIA Technical Note 16 – Welding Stainless Steel
- WTIA Technical Note 18 – Welding of Castings

APPENDIX A - TEMPLATES FOR PQR AND WPS

These templates shall be used when specifying a PQR and WPS.

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PROCEDURE QUALIFICATION RECORD

Material spec/grade	to
Fabricator Process Welding Standard Edge preparation Weldability group No. Specimen thickness	PQR no. PQR-SHL-xx-xx Date qualified Welded by Revision Date Qualified position

Preheat temperature Inter-run temperature Type and check method	PWHT Hold Other

Run sequence	Joint details	
		Prequal join No. To Table Root gap G mm Root face F_r mm Incl. angle Θ^0 Backing

Specification - Root	Remainder	Consumable Detail: Stickout: Shield Gas: Electrode: Diameter: Filler Wire: Batch#
Classification - Root	Remainder	
Shielding gas	Flow rate	
Purge gas	Flow rate	

Weld run details					Welding parameters						
No.	Side	Position	Size	Weld Process	Gas Flow L/mm	Amps	Voltage	Polarity	Interpass Temp ^{0}C	Speed mm/min	Heat Input kJ/mm

Technique: Stringer/Weave Intitial cleaning Inter-run clean Nozzle size	Backgouge method Backgouge check	Non Destructive Testing: Visual MPI UT RT

Test Results

Test type	Visual	Macro	Tensile	Bend	Charpy V	Hardness	Other
Test by							
Report No.							

Result							
Notes/revisions							
Rev.	Date	Description	Checked	Prepared by		Reviewed by	

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WELDING PROCEDURE SPECIFICATION		
Material specification/grade	to	
Fabricator		WPS No. WPS-SHL-xx-xx
Standard AS/NZS		Date
Process		PQR No.
Edge preparation		Page
Welding direction		Revision Date
Range qualified		
Preheat temperature		PWHT
Method and check method		Hold
Inter-run temperature (max.)		Other
Joint sketch	Run Sequence	Joint Tolerance Prequal join No. To Table Root gap G mm Root face F_r mm Incl. angle Θ^0 Backing

Welding Consumables		
Specification - Root	Remainder	Flux
Classification - Root	Remainder	
Shielding gas	Flow rate	
Purge gas	Flow rate	

Weld run details					Welding parameters						
No.	Side	Position	Size	Weld Process	Gas Flow L/min	Amps	Voltage	Polarity	Interpass Temp ^{0}C	Speed mm/min	Heat input kJ/mm

Technique: Stringer/weave Initial cleaning Inter-run clean Nozzle size	Backgouge method Backgouge check	Non Destructive Testing: Visual MPI UT RT PT

Notes/revisions							
Rev.	Date	Description	Checked	Prepared by		Reviewed by	
				Client Approval		Third Party	

APPENDIX B - PREHEAT TEMPERATURE

TABLE 5.3.4(A)

PREHEAT DETERMINATION

Parent		Weldability group number
Standard	Grade (see Note 1)	
AS/NZS 1163	C250 C350, C450	1 4
AS 1397	G250 G300, G350 G450	1 5 4
AS 1450	C200, H200 C250, H250 C350, H350 C450	1 4 5 4
AS 1548	PT430, PT460 PT490, PT540	4 5
AS/NZS 1594 (see Note 2)	HA1, HA3, HA4, HA200, HA250/1 HA250, HU250 HA300, HA300/1, HU300, HU300/1, XF300 HA350 HW350 (See Note 2) HA400 XF400 XF500 HA1006, HA1010 HA1016, HXA1016	1 3 3 4 5 4 3 4 1 3
AS/NZS 1595	All	1
AS 2074	C1 C2 C3 C4-1 C4-2 C7A-1 C7A-2	5 2 6 5 6 4 5
AS/NZS 3678 and AS/NZS 3679.2	200 250, 300 350, WR350 (see Note 2), 400, 450 A1006 XK1016	1 4 5 1 4
AS/NZS 3679.1	300 350	4 5

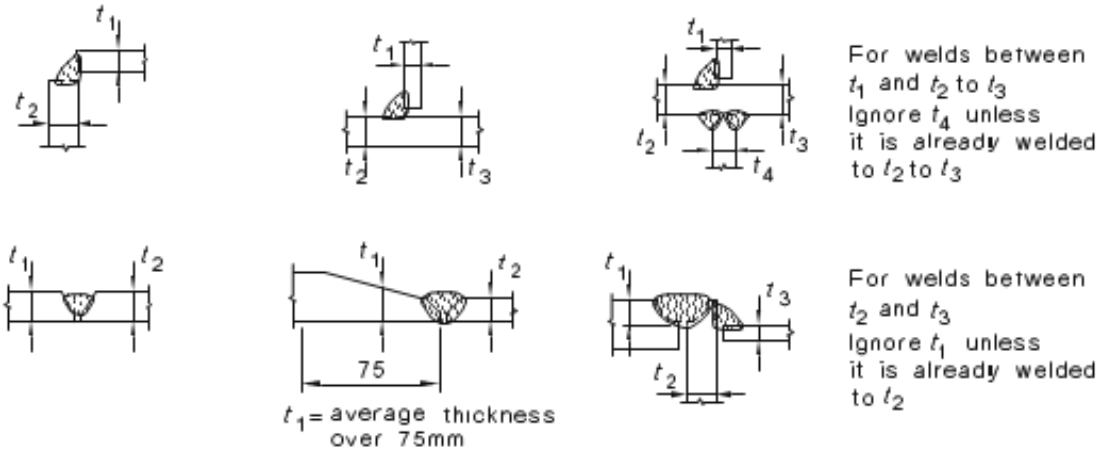
NOTES:

1. The weldability of each impact tested steel variant is the same as its base steel.
2. Weldability Group Number 5 for HW350 and WR350 steels is based on the typical maximum carbon equivalent encountered in Australia and New Zealand, rather than the maximum specification limits normally applied

TABLE 5.3.4(B)

RELATIONSHIP BETWEEN CARBON
EQUIVALENT AND GROUP NUMBER

Carbon equivalent	Group number
<0.30	1
⩾0.30 <0.35	2
⩾0.35 <0.40	3
⩾0.40 <0.45	4
⩾0.45 <0.50	5
⩾0.50 <0.55	6
⩾0.55 <0.60	7
⩾0.60 <0.65	8
⩾0.65 <0.70	9
⩾0.70 <0.75	10
⩾0.75 <0.80	11
⩾0.80 --	12



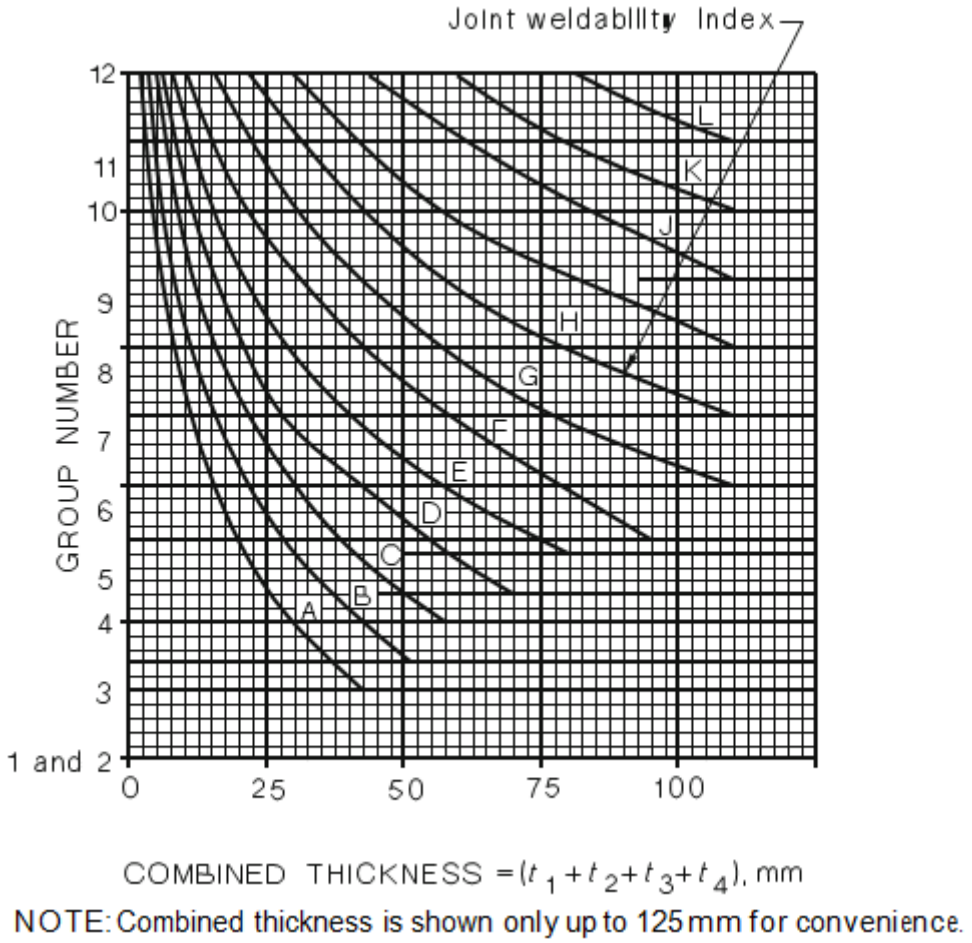


FIGURE 5.3.4(A) RELATION OF JOINT WELDABILITY INDEX TO JOINT COMBINED THICKNESS AND GROUP NUMBER

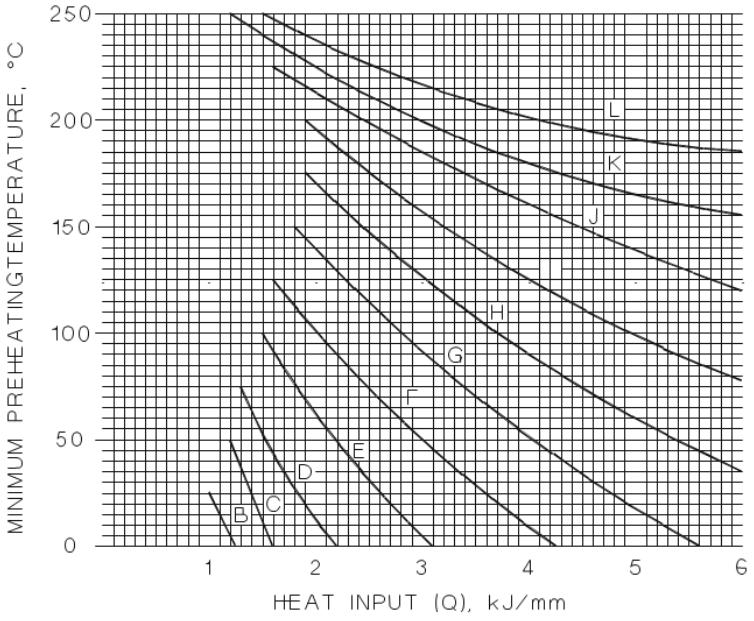


FIGURE 5.3.4(B) PREHEATING DETERMINATION FOR HYDROGEN-CONTROLLED MANUAL METAL-ARC ELECTRODES AND SEMI-AUTOMATIC OR AUTOMATIC PROCESSES

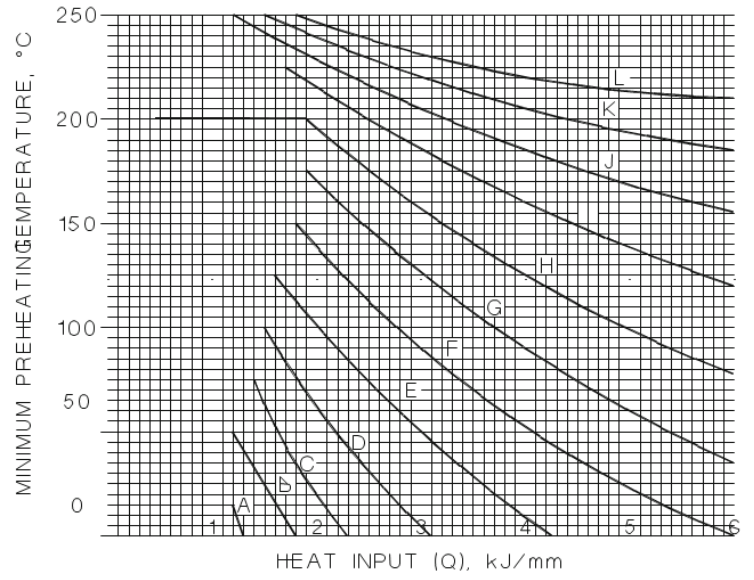


FIGURE 5.3.4(C) PREHEATING DETERMINATION FOR MANUAL METAL-ARC ELECTRODES OTHER THAN HYDROGEN CONTROLLED

APPENDIX C - SURFACE FINISH

Head	Surface Finish
< 300 feet (91m) 300-1000 feet (91-305m) 1000 feet (305m)	250 u in. (6.3 u m) 120 u in. (3.2 u m) 90 u in. (2.3 u m)