WTIA Technical Note No. 1

The Weldability of Steels

The WTIA National Diffusion Networks Project is supported by Federal, State and Territory Governments and Australian industry

EXPERT TECHNOLOGY TOOLS for the Welding Industry

What are they?

An Expert Technology Tool (ETT) is a medium for diffusion and take-up of technological information based on global research and development (R&D) and experience to improve industry performance.

It can be formatted as a hard copy, software (fixed, interactive or modifiable), audiovisual (videos and sound tapes) or physical samples. It can be complemented by face-to-face interaction, on-site and remote assistance, training modules and auditing programs.

The diagram overleaf and the information below show how the WTIA has introduced a group of ETTs to help companies improve their performance.

ETTs and the SME – how can they help my Total Welding Management System?

A Total Welding Management System (TWMS) is a major ETT with supporting ETTs created specifically to assist Australian industry, particularly those Small to Medium Enterprises (SMEs) that do not have the time or finance to develop an in-house system. These companies, however, are still bound by legal requirements for compliance in many areas such as OHS&R, either due to government regulation or to contract requirements. The TWMS developed by the WTIA can be tailor-made by SMEs to suit any size and scope of operation, and implemented in full or in part as required.

What is Total Welding Management?

Total Welding Management comprises all of the elements shown in the left-hand column of the table shown overleaf. Each of these elements needs to be addressed within any company, large or small, undertaking welding, which wishes to operate efficiently and be competitive in the Australian and overseas markets.

The Total Welding Management System Manual (itself an Expert Technology Tool) created by the WTIA with the assistance of industry and organisations represented within a Technology Expert Group, overviews each of these elements in the left-hand column. It details how each element relates to effective welding management, refers to supporting welding-related ETTs, or, where the subject matter is out of the range of expertise of the authors, refers the user to external sources such as accounting or legal expertise.

Knowledge Resource Bank

The other columns on the diagram overleaf list the Knowledge Resource Bank and show examples of supporting ETTs which may, or may not, be produced directly by the WTIA. The aim, however, is to assist companies to access this knowledge and to recognise the role that knowledge plays in a Total Welding Management System. These supporting ETTs may take any form, such as a Management System e.g. Occupational Health, Safety and Rehabilitation (OHS&R), a publication e.g. WTIA Technical Note, a video or a Standard through to software, a one-page guidance note or welding procedure.

Clearly, ETTs such as WTIA Technical Notes, various Standards, software, videos etc are readily available to industry.

The group of ETTs shown overleaf relate to a general welding fabricator/contractor. The ETT group can be tailor-made to suit any specific company or industry sector.

A company-specific Knowledge Resource Bank can be made by the company omitting or replacing any other ETT or Standard.

Total Welding Management for Industry Sectors

Total Welding Management Systems and the associated Knowledge Resource Banks are being developed for specific industry sectors, tailored to address the particular issues of that industry and to facilitate access to relevant resources. A company-specific Total Welding Management System can be made by the company adding, omitting or replacing any element shown in the left hand column, or ETT or Standard shown in the other columns. This approach links in with industry needs already identified by existing WTIA SMART Industry Groups in the Pipeline, Petrochemical and Power Generation sectors. Members of these groups have already highlighted the common problem of industry knowledge loss through downsizing, outsourcing and privatisation and are looking for ways to address this problem.

The concept of industry-specific Total Welding Management Systems and Knowledge Resource Banks will be extended based on the results of industry needs analyses being currently conducted. The resources within the Bank will be expanded with the help of Technology Expert Groups including WTIA Technical Panels. Information needs will be identified for the specific industry sectors, existing resources located either within Australia or overseas if otherwise unavailable, and if necessary, new resources will be created to satisfy these needs.

How to Access ETTs

Management System ETTs, whether they are the Total Welding Management Manual (which includes the Quality Manual), OHS&R Managers Handbook, Procedures, Work Instructions, Forms and Records or Environmental Improvement System, can be accessed and implemented in a variety of ways. They can be:

- Purchased as a publication for use by industry. They may augment existing manuals, targeting the welding operation of the company, or they may be implemented from scratch by competent personnel employed by the company;
- Accessed as course notes when attending a public workshop explaining the ETT;
- Accessed as course notes when attending an in-house workshop explaining the ETT;
- Purchased within a package which includes training and on-site implementation assistance from qualified WTIA personnel;
- Accessed during face-to-face consultation;
- Downloaded from the WTIA website www.wtia.com.au

ETTs created by the WTIA are listed on page 42 of this Technical Note. Call the WTIA Welding Hotline on 1800 620 820 for further information.

TOTAL WELDING MANAGEMENT SYSTEM
supported by KNOWLEDGE RESOURCE BANK

TOTAL WELDING MANAGEMENT SYSTEM MANUAL
ETT: MS01
(Including Welding Quality Management System)

KNOWLEDGE RESOURCE BANK
i.e. resources for the Total Welding Management System

ETTs: MANAGEMENT SYSTEMS | ETTs: OTHER RESOURCES | ETTs: STANDARDS

ELEMENTS:

Element	ETTs: MANAGEMENT SYSTEMS	ETTs: OTHER RESOURCES	ETTs: STANDARDS
1. Introduction			
2. References			
3. Management System		TN19 Cost Effective Quality Management	AS/NZS ISO 9001 AS/NZS ISO 3834
4. Management Responsibilities (including Risk Management)		TN19 Cost Effective Quality Management	AS 4360
5. Document Control			
6. Production Planning			
7. Contracts			
8. Design		TN6 Control of Lamellar Tearing TN8 Economic Design of Weldments TN10 Fracture Mechanics TN12 Minimising Corrosion TN13 Stainless Steels for Corrosive Environments TN14 Design & Construction Steel Bins	AS 4100 AS 1210 BS 7910
9. Purchasing (including Sub-Contracting)			
10. Production & Service Operations		TN1 Weldability of Steels TN2 Successful Welding of Aluminium TN4 Hardfacing for the Control of Wear TN5 Flame Cutting of Steels TN9 Welding Rates in Arc Welding TN11 Commentary on AS/NZS 1554 TN15 Welding & Fabrication Q&T Steels TN16 Welding Stainless Steels TN17 Automation in Arc Welding TN18 Welding of Castings TN21 Submerged Arc Welding Videos – Welding Parts A & B PG02 Welding of Stainless Steel	AS/NZS 1554 AS 1988
11. Identification and Traceability		TN19 Cost Effective Quality Management	
12. Welding Coordination			ISO 14731
13. Production Personnel			
14. Production Equipment			
15. Production Procedures		TN1 The Weldability of Stee TN9 Welding Rates in Arc Weldingl TN19 Cost Effective Quality Management	
16. Welding Consumables		TN3 Care & Conditioning of Arc Welding Consumables	
17. Heat Treatment			AS 4458
18. Inspection and Testing		PG01 Weld Defects	AS 2812
19. Inspection, Measuring and Test Equipment			
20. Non-Conforming Product			
21. Corrective Action		TN20 Repair of Steel Pipelines	AS 2885
22. Storage, Packing and Delivery			
23. Company Records		TN19 Cost Effective Quality Management	
24. Auditing			
25. Human Resources			
26. Facilities			
27. Marketing			
28. Finance			
29. OHS&R	MS02 OHS&R – Managers Handbook MS03 OHS&R – Procedures MS04 OHS&R – Work Instructions MS05 OHS&R – Forms & Records	TN7 Health & Safety in Welding TN22 Welding Electrical Safety Fume Minimisation Guidelines Video – Fume Assessment	AS 4804
30. Environment	MS06 Environmental Improvement MS	TN23 Environmental Improvement Guidelines for Welding	AS/NZS 14001
31. Information Technology			
32. Innovation, Research and Development			
33. Security			
34. Legal			

Note 1: Examples of ETTs listed are not all-embracing and other ETTs within the global information supply can be added.

Note 2: Dates and titles for the ETTs listed can be obtained from WTIA or SAI

This Technical Note:

- is a revision of Technical Note 1 – 1996 Edition
- is intended to assist welders, fabricators, supervisors, inspectors and designers on the welding and weldability of steels presently in-service in Australia;
- has been prepared by WTIA under the direction of its Project Panel 2; "Welding Metallurgy", currently consisting of:
  Mr Rick Kuebler – Lincoln Electric Co. (Aust) Pty Ltd – Convener
  Mr Russell Barnett – Bisalloy Steels Pty Ltd
  Mr Ian Brown – University of Adelaide
  Mr Bruce Cannon – BlueScope Steel Ltd
  Mr Hayden Dagg – OneSteel Market Mills
  Mr Alistair Forbes – BOC Gases Australia Ltd
  Mr Bruce Hamm – HRL Technology Pty Ltd
  Mr Peter Howard – CBI Constructors Pty Ltd
  Dr Huijin Li – Australian Nuclear Science and Technology Organisation (ANSTO)
  Prof Valerie Linton – University of Adelaide
  Dr David Nolan – University of Wollongong
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Future Revisions

This Technical Note will be revised from time to time and comments aimed at improving its value to industry will be welcome.

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Introduction

Experience indicates that there is a continuing demand from industry for up-to-date practical guidance on the weldability of steels. This is particularly so in view of the increased range of steels now used in Australia and the new steels and specifications recently introduced. The demand also arises from conflicting data from a number of sources, which indicates the need for soundly based information on the level of pre-heating required under various welding conditions.

Weldability is defined in Australian Standard AS 2812 as 'The capacity of a metal to be welded, under the fabrication condition imposed, into a specific, suitably designed structure and to perform satisfactorily in the intended service.'

The above definition implies many significant factors, however, one of the most important in welding of steels is the adoption of welding procedures which will secure integrity in the Heat-Affected Zone (HAZ) to ensure that the structure will adequately achieve its intended service performance.

The use of pre-heat prior to welding is an industry standard practice to control the integrity of the HAZ. This document provides the guidelines necessary to determine the level of pre-heat required.

The Technical Note is a revision of the 1996 edition.

SCOPE

This Technical Note gives recommendations for the control of HAZ hardness and avoidance of cold cracking in carbon, carbon-manganese and low-alloy steels. Cold cracking may also be known as “Delayed Cracking”, “Hydrogen Induced Cracking”, or “Hydrogen Assisted Cold Cracking”. This document provides guidelines on avoidance of cold cracking and on the weldability and pre-heat requirements of constructional steels based on the following factors (Reference 1):

1) Carbon Equivalent of the steel and its related Group Number;
2) Thickness and joint type of the weldment to be fabricated;
3) Welding energy input provided by the welding process;
4) Expected Hydrogen content of the welding process.

The data in this Technical Note is applicable to the common arc welding processes such as manual metal arc welding (MMAW), gas metal arc welding (GMAW), flux cored arc welding (FCAW), gas tungsten arc welding (GTAW), and submerged arc welding (SAW). Note that with the use of run-on tabs and the high energy input used with electroslag and electrogas processes, preheating is not normally required.

The use of controlled welding energy input and preheat for the control of notch toughness, joint strength, or for the avoidance of hot cracking, is outside the scope of this Technical Note.

The level of pre-heat is dependent on the Group Number of the steel, the heat input applied during welding, the hydrogen level in the weld and the degree of restraint.

The Group Number system in this Technical Note has 12 groups arranged in 0.05% Carbon Equivalent increments ranging from <0.30 to 0.80 and greater.

For further guidance in the welding of steels other than carbon, carbon-manganese and low alloy steels, the user is referred to the WTIA’s Technical Notes as listed below:

(i) Welding of quenched and tempered steels - Technical Note 15;

(ii) Welding of stainless steels - Technical Note 16;

(iii). Welding of castings - Technical Note 18.

For all other steels, the user is advised to contact the WTIA for advice on welding and weldability.

Confidence in Preheat Recommendations

The preheat recommendations in this Technical Note for avoidance of cold cracking are based on:

1. Carbon Equivalent (CE) of weldable constructional steels;
2. Consideration of heat loss rate via equivalent joint thickness;
3. Welding Heat Input (kJ/mm);
4. Hydrogen potential of process and consumables;
5. Controlled Thermal Severity test (CTS) data (Refer BS 7363 for guidance);
6. HAZ hardness correlations with cold cracking susceptibility; and,
7. Extensive service experience.

Although the preheat recommendations can be used with a high level of confidence, they cannot guarantee that cracking will never occur.

The preheat and weldability recommendations provided do not over-ride the obligation to demonstrate suitability of welding procedures through the use of procedure qualification tests as prescribed by the applicable fabrication standards. Additionally, it is assumed welding is performed by competent welders e.g capable of complying with the minimum requirements of AS/NZS 1554.1 Section 4.11.2 Welder Qualifications.

Readers familiar with the concepts of Group Number (Section 4), combined thickness (Section 5), welding energy input (Section 6), hydrogen content of welds (Section 7), preheat requirements (Section 8) and associated limitations, can proceed directly to Section 9 of this Technical Note for instructions on determining preheat and/or minimum welding energy input.

Historically the need for preheat during the welding of ferritic steels has been dictated by the susceptibility of the Heat Affected Zone (HAZ) to cold cracking. It was assumed that procedures that provided freedom from HAZ cold cracking also provided freedom from cold cracking in the weld metal. Consequently, current welding Standards and WTIA Technical Note 1 are based entirely on the avoidance of HAZ cracking and do not provide guidance for the avoidance of cold cracking in the weld metal.

Recent advances in the production of 'clean' lower carbon equivalent steels have reduced the risk of cold cracking in the HAZ, and in some instances, weld metal cold cracking is more likely than HAZ cracking. Moreover, it is becoming apparent that some measures that reduce the risk of HAZ cracking, such as high heat input, can increase the risk of weld metal cracking, especially when welding highly restrained thick section (greater than 20 mm) structures.

Whilst there is a considerable research effort under way investigating this problem, the prevention and control mechanisms for weld metal cracking are yet to be quantified. Typically, weld metal cracking is transverse to the weld direction and can be either sub-surface or surface breaking. Detection using conventional radiographic and ultrasonic techniques is sometimes difficult and unreliable. To detect such cracks ultrasonically, it is necessary to remove the weld reinforcement to provide a flat surface for probe engagement and allow the ultrasonic beam to reflect from the planar imperfections laying transverse to the direction of welding.

In comparison with manual metal arc welding, the flux cored arc welding process has an additional set of welding parameters that influence the final weldment hydrogen content (Reference 2). These include welding voltage, contact tip to work distance, wire feed speed (current), polarity and the shielding gases used. Their interactions are complex and the mechanism of the cold cracking that may result is yet to be fully determined. Reduced contact tip working distance and increased welding current reduce the time the wire spends in the resistive heating zone thereby increasing the final weld metal hydrogen content and increasing the risk of cracking.

Likewise, it is known that in addition to atmospheric conditions (Reference 3), surface contaminants (see Chapter 7 of this Technical Note), remnant lubricants on wire from the manufacturing process, and residue from spatter release fluids (Reference 4), decompose in the arc and raise the weld metal hydrogen levels, even when using very low hydrogen (H5) welding consumables.

Cold cracking typically occurs within 24 to 48 hours of the completion of welding (Reference 5), but may occur many days after the weld has been completed (one recent incident in high strength weld metal occurred 30 days after welding). The minimum time delay required prior to final non-destructive examination being carried out after completion of welding should therefore be given appropriate consideration.

Group Number Determination and Relative Weldability

The Group Number concept for steels is based on a grading derived from the steels chemical composition It has been introduced for the identification of the relative weldability of steels normally used by Australian Industry.

The Group Number system used is presented in Table 4.1, and is based on the Carbon Equivalent (CE) calculated from the International Institute of Welding (IIW) formula:

$$CEQ = C + \frac{Mn}{6} + \frac{Cr+Mo+V}{5} + \frac{Ni+Cu}{15}$$

The IIW formula does not include either Sulphur or Boron. These elements are discussed in Appendix C. As the CE increases, the relative weldability decreases, invoking the recommendation for use of hydrogen controlled welding processes through to post weld stress relief, and associated removal of diffusible hydrogen from weld zones.

Table 4.1 Relationship Between Carbon Equivalent and Group Number and Weldability

Carbon Equivalent	Group Number	Weldability *
below 0.30	1	O
0.30 to below 0.35	2	O
0.35 to below 0.40	3	O
0.40 to below 0.45	4	H/O
0.45 to below 0.50	5	H/O
0.50 to below 0.55	6	H
0.55 to below 0.60	7	H
0.60 to below 0.65	8	HSCSR
0.65 to below 0.70	9	HSCSR
0.70 to below 0.75	10	HSCSR
0.75 to below 0.80	11	HSCSR
0.80 and above	12	NR

The allocation of Group Number to a steel is described in Table 4.2 next page.

*** Key to weldability**

- O – Any electrode type or welding process is satisfactory.
- H/O – Hydrogen controlled electrodes or semi-automatic processes are recommended, but rutile or other electrodes maybe used.
- H – Hydrogen controlled electrodes or semi-automatic or automatic processes are essential for good welding.
- SC – Slow cooling from welding or preheat temperature is recommended.
- SR – Postweld heat treatment (stress relief) is suggested for high quality work, particularly where severe service conditions apply to the component.
- NR – Welding is generally not recommended.

Table 4.2 Allocation Group Number for Steel

Situation		Allocation
1	Standard steel of known Specification. Heat or Product Analysis may not be known.	Refer to Table 9.1 for the Group Number
2	Steel (listed in Table 9.1) of known heat analysis.	Calculate the CEQ and add 0.01 to the value, then select the Group Number from Table 4.1.
3	Product Analysis known for the steel and composition within the range of Table 9.1.	Calculate the CEQ and add 0.02 to the value and then select the Group Number from Table 4.1.
4	Steel of known heat analysis but specification not listed in Table 9.1.	Calculate CEQ and add 0.02 to the value, then select the Group Number from Table 4.1.
5	Steel to a Specification not listed in Table 9.1, but within the composition range covered by the Table. Specific heat / product analysis unknown.	
	a) C, C-Mn, or C-Mn-Microalloy	a) Calculate CEQ based on maximum specification limits, then obtain the Group Number from Table 4.1.
	b) Low alloy steel	b) Calculate CEQ based on maximum specification limits, and then use 0.85 of this value to obtain the Group Number from Table 4.1.

Note: 1. The product analysis method is only valid for analyses determined using precision laboratory methods operating in tightly controlled calibrated circumstances. The usage and suitability of the statistically based safety factor given for analysis variation (0.02) has not been established for analyses determined using portable spectrographic equipment.

2. The suitability of using the heat analyses and product analyses methods for preheat determination has not been established for castings. Reference should be made to WTIA Technical Note 18 for preheat determination.

Combined Thickness

The concept of combined thickness is required to address the cooling rate, caused by the abutting or mating sections forming a weld joint. The combined thickness is shown for a range of joints in Figure 5.1 and calculated using the formula:

$$T_C = t_1 + t_2 + t_3 + t_4$$

Parts to be joined which are less than 75 mm wide, have a limited heat capacity. The use of their full thickness in determining combined thickness may lead to the calculation of unnecessarily high preheat. A more appropriate estimation of effective combined thickness may be made by assuming that the part less than 75 mm wide is replaced by a plate 75 mm wide of the same cross-section as shown in Figure 5.2 below. The formula to calculate the effective thickness is:

$$T_E = \frac{W \text{ x } t}{75}$$

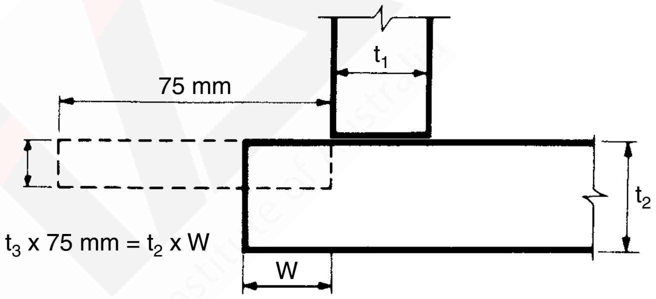
Where

W is the width of the part (less than 75mm)

t is the actual thickness of the part.

T_E is the effective thickness for calculation purposes

For example:



Effective combined thickness equals $t_1 + t_2 + \frac{W \text{ x } t_2}{75}$

Figure 5.2 – Effective combined thickness.

When bars or rod sections are welded, often their widths or diameters are less than 75 mm, and an appropriate method for calculating equivalent thickness is to equate the areas to a rectangular section with a width of 75 mm. The formula to convert a round section of diameter d (in mm) to an effective thickness, TE, is TE=0.01d2 which is derived by:

$$T_E = \frac{\pi \text{ x } d^2}{4 \text{ x } 75}$$

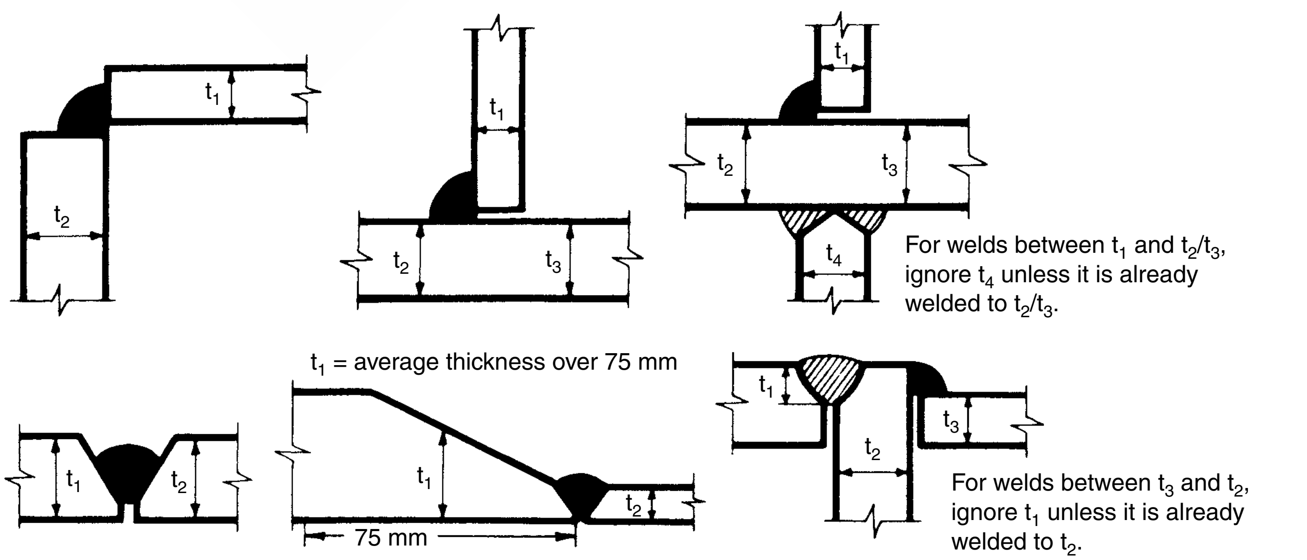


Figure 5.1 – Calculation of combined thickness.

For welded joints using permanent backing bars, an adjustment in Combined Thickness is not normally considered necessary as the relative size of the backing bar is very small and thus has minimal affect on cooling rates. If the size of the backing bar is considered significant, the technique shown in Figure 2 can be used to give an effective thickness which is then included when calculating the combined thickness.

To calculate the combined thickness, the number of heat paths that will effect the weld cooling rate need to be determined. (see Diagram 1)

Next add the various part thicknesses or effective thicknesses to obtain the combined thickness. For example, for a butt weld in equal thickness plates would have a combined thickness of 2*t* (i.e. twice the plate thickness) and for a fillet weld in equal section plates the combined thickness is equivalent to 3*t*.

Restraint

The level of restraint provided for in these recommendations is moderate. For joints with high restraint, e.g. joints in short, thick, (and hence rigid) components, an increase up to 50°C over the calculated preheat temperature is advisable.

Fit-Up

Joint gap tolerances are specified in AS/NZS 1554. Where the gap between parts to be welded is very small, e.g. as in close-fitting small machined parts, some relaxation of preheat temperature may be allowable.

WELDING ENERGY INPUT

For electric arc welding, the welding energy input is based on the following formula:

$$Q = \frac{I \times E}{s} \times \frac{60}{1000}$$

Where Q = welding energy input, kJ / mm

E = arc voltage, V (RMS value for a.c.)

I = welding current, A (RMS value for a.c.)

s = welding speed, mm/min

Arc voltage and welding current can often be read off the welding machine during welding. External voltmeters and ammeters specifically for measuring welding outputs can also be used. Travel speed is generally measured directly by measuring the length of weld deposited over a given time.

Figures D1 and D2 in Appendix D are nomographs to facilitate calculation, particularly for semi-automatic and automatic processes. Figures D3 to D6 in Appendix D translate this formula into more practical terms for manual arc welding, using the results of extensive investigations (Reference 4).

The efficiency of heat transfer from the welding arc to the weld joint is considered on the basis of similar welds made by the manual metal arc process.

Hydrogen Control and Welding Processes

Hydrogen Controlled Consumables and Low Hydrogen Welding Processes

Hydrogen controlled consumables produce less than 15 mL/100g of diffusible hydrogen (H_D) in the weld metal. For the purpose of this Technical Note, the controlled hydrogen processes include:

1. Manual Metal Arc Welding (MMAW) using EXX15, EXX16, EXX18, EXX28 and EXX48 electrodes having typically H_D 5-15mL /100g of deposited weld metal;
2. Gas Tungsten Arc Welding (GTAW) having typically H_D < 1 mL/100g of weld metal;
3. Gas Metal Arc Welding (GMAW) having typically H_D < 3 mL/100g of deposited weld metal;
4. Flux Cored Arc Welding (FCAW) gas shielded using seamless cored wire electrodes having typically <5 mL/100g of deposited weld metal;
5. FCAW gas shielded using metal cored wires having typically H_D 5 – 10 mL/100g of deposited weld metal;
6. FCAW gas shielded using seamed cored wire electrodes having typically H_D 5 – 15 mL/100g of deposited weld metal;
7. FCAW self shielded using seamed cored wire electrodes has hydrogen potential typically H_D 6-15 mL/100g of deposied weld metal;
8. Submerged Arc Welding (SAW) typically H_D 3-8 mL/100g of deposited weld metal provided new dry flux is used.

Data for welding with hydrogen controlled flux coated or cored consumables include some allowance for the presence of a limited moisture content, as it is considered that full drying of fluxes to very low moisture levels is not always achievable. Consumables for semi-automatic and automatic processes are assumed to be used strictly in accordance with the manufacturers' recommendations. Also, all welding must be carried out on clean, dry work, free from oil or other substances having hydrogen generation potential. For further information refer to the latest edition of WTIA Technical Note 3 "Care and Conditioning of Arc Welding Consumables" and Appendix B.

Non Hydrogen Controlled Consumables & Welding

MMAW using EXX10, EXX11, EXX12, EXX13 and EXX24 electrodes are considered to be non hydrogen controlled. In fact, cellulosic electrodes (EXX10 and EXX11) generate copious quantities of hydrogen to produce the arc characteristic for root pass welding of pipe joints.

Also hydrogen controlled consumables that have not been stored, dried or used in accordance with manufactures' recommendations or any welding process carried out using contaminated consumables or on materials contaminated with oil, grease, water or other hydrocarbon containing substances can result in a loss of hydrogen control.

Anti-Spatter Materials

Anti-spatter sprays and liquids must be used with particular care so as to avoid contaminating any area in or near the weld zone. Such contamination will increase the weld metal hydrogen level, which may then give rise to the occurrence of HAZ cold cracking and other welding defects (Reference 5).

Preheat and Postheat Requirements

Preheat Temperature

Preheat is the temperature of the joint just prior to being welded. This temperature must extend over a distance at least equal to the thickness of each part at the weld but not less than 75 mm both laterally and in advance of the welding of each run. The preheat temperatures recommended in this Technical Note are minimum values, but recommended preheat temperatures should not be greatly exceeded as this unnecessarily increases cost and often results in excessive distortion.

AS/NZS 1554.1 recommends that preheat temperature be maintained for the duration of welding, although in certain circumstances it may be acceptable for the weldment to be reheated to preheat temperature prior to recommencement of welding after a prolonged break.

Preheat temperatures are actual weldment temperatures, not increases or differentials above ambient temperature.

Interpass Temperature

In multipass welding, the interpass temperature may substantially exceed the preheat temperature where allowed by the application standard. The Welding Procedure Specification should provide guidance on limiting the interpass temperature, and the welding operator may need to stagger the welding passes to allow the workpiece temperature to reduce to a value between the preheat temperature and the maximum interpass temperature.

Preheat for Welding in Low Ambient Temperature Environment

When the ambient temperature or parent metal temperature is below 0°C, the parent metal should be preheated to at least 25°C and maintained at or above this temperature during welding. With oxygen -fuel gas or air-propane flame preheating, a higher minimum preheat temperature is necessary (typically 60°C) to ensure water vapour condensation is avoided.

Measurement of Preheat Temperature

Preheat temperature should be measured by either temperature indicating crayons, a contact thermometer, thermocouple probe or other accurate means, immediately prior to commencement of welding. Before measuring the temperature of any surface being directly heated, the heat source should be removed to allow equalising of temperature, i.e. 1 min for each 25 mm thickness of the part. Temperature indicating crayons must not be applied to joint surfaces to be part of the weld joint. Guidance on the measurement of preheat is now available via the Standard AS ISO 13916 (Reference 6).

Preheating Methods

Preheating may be carried out using gas burners or torches, electric elements, induction elements, electric ovens, or other approved methods, provided they give a satisfactory temperature distribution and do not interfere with welding operations. It is recommended that, where possible, heating be applied to the back of the surfaces to be welded to ensure adequate and reasonably uniform temperature, as shown in Figure 8.1.

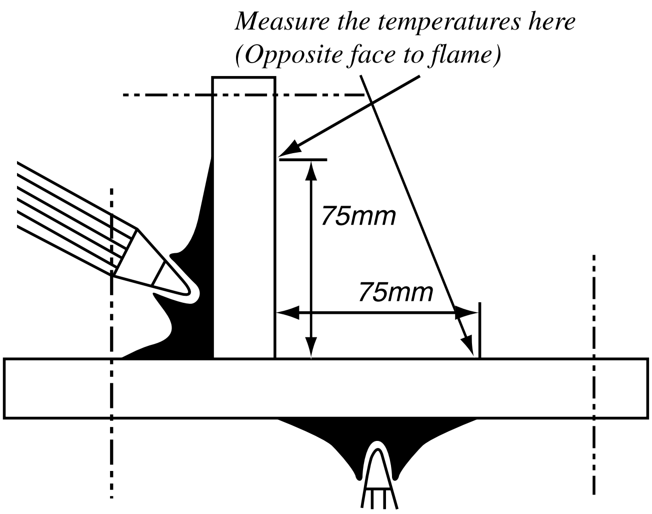


Figure 8.1 Flame preheating to ensure through-thickness heating

Standardised Preheat

Where a number of joints of much the same thickness and material are made, a standard or "blanket" preheat may be adopted for ease of application and control.

Uniform and Local Preheat

The recommendations in this Technical Note assume that preheat is reasonably uniform, ie: temperature gradients are small and thermal stresses induced in the joint on cooling are small. This occurs where the whole component, or a complete band around the component and incorporating the joint, is heated, e.g. for a butt weld in a column, the whole section around the joint is preheated. Where the preheat is applied locally, e.g. to one flange only of a column or beam, some increase in preheat temperature may be needed to counteract any contraction stresses on cooling.

Cooling after welding

Cooling to ambient after welding is completed should be reasonably slow and uniform, comparable with that obtained under normal shop conditions. Where cooling would be accelerated by weather conditions or location etc., for example on the back of a plate, suitable allowances should be made by increased heat input, by higher preheating or by weather protection or blanketing the weldment to reduce cooling rates in special circumstances insulation maybe useful in reducing the normal cooling rate.

Post-heating

Maintenance of preheat temperatures after welding where indicated in Table 3, or between runs, will further reduce the risk of HAZ cracking, because diffusible hydrogen can more readily escape from the weld region. In special cases it may be necessary to maintain preheat temperatures until all welding is completed and post weld heat treatment (stress relief) is initiated.

Procedure for Determining Preheat and Minimum Welding Energy Input

9.1 General Procedure

To find the welding energy input or the preheat temperature required for use with a particular welding process on a particular steel weldment, the steps given below need to be followed.

It is important to note that tack welds, whether they are to be ultimately incorporated in the weld or not, must be regarded in the same manner as production welds. A higher energy input or preheat may be required for short tack welds to compensate for the accelerated cooling rate associated with short runs on heavy weldments.

Where the steel to be welded is line pipe steel, Chapter 10 should be considered in conjunction with this Section.

Step 1: From Table 9.1, find the **Group Number** for the steel grade or composition. For joints containing different steels, use the higher Group Number. For steels not listed in Table 9.1 see Chapter 4.

Step 2: Using Figure 5.1 in Chapter 5, calculate the **Combined Thickness** of the joint.

Step 3: From Figure 9.1, find the closest curve to the intersection of **Combined Thickness** and **Group Number**. This curve designates the **Joint Weldability Index** letter (A – L).

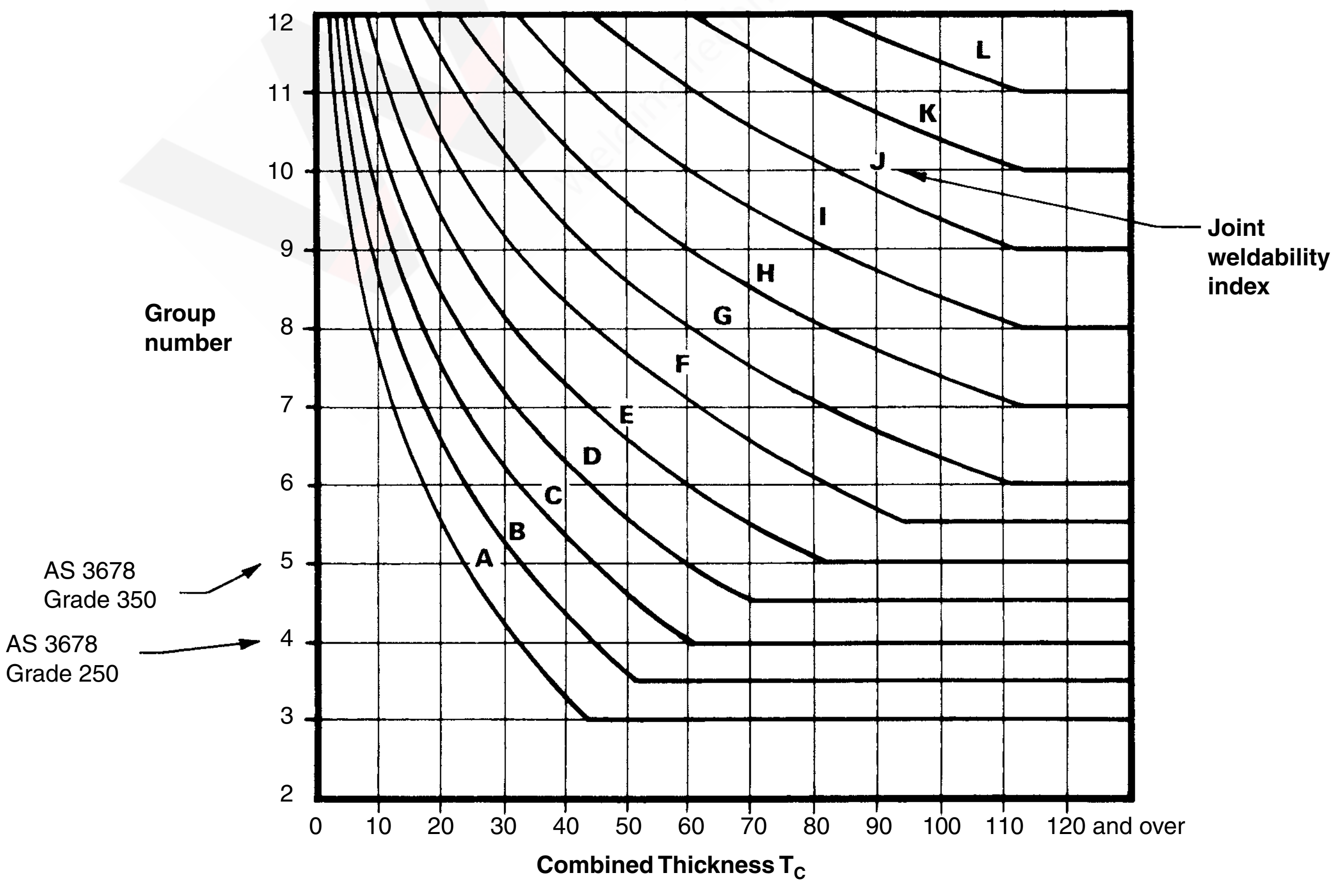


Figure 9.1 Determination of preheat requirements for hydrogen controlled consumables and proces

Step 4: Using the information on process operating conditions (current, voltage and welding speed) in the **Welding Procedure Specification**, calculate the nominal **Welding Energy Input** using the formula in Chapter 6.

Step 5: From Figure 9.2, for hydrogen controlled processes, or from Figure 9.3, for other than hydrogen controlled processes, and using the curve bearing the same **Joint Weldability Index** letter found from Step 3, read off the **Preheat Temperature** for the **Welding Energy Input** as determined in Step 4.

Step 6: Practical welding variables can be selected for a more productive **Welding Energy Input** to minimise or eliminate the need for **Preheat**.

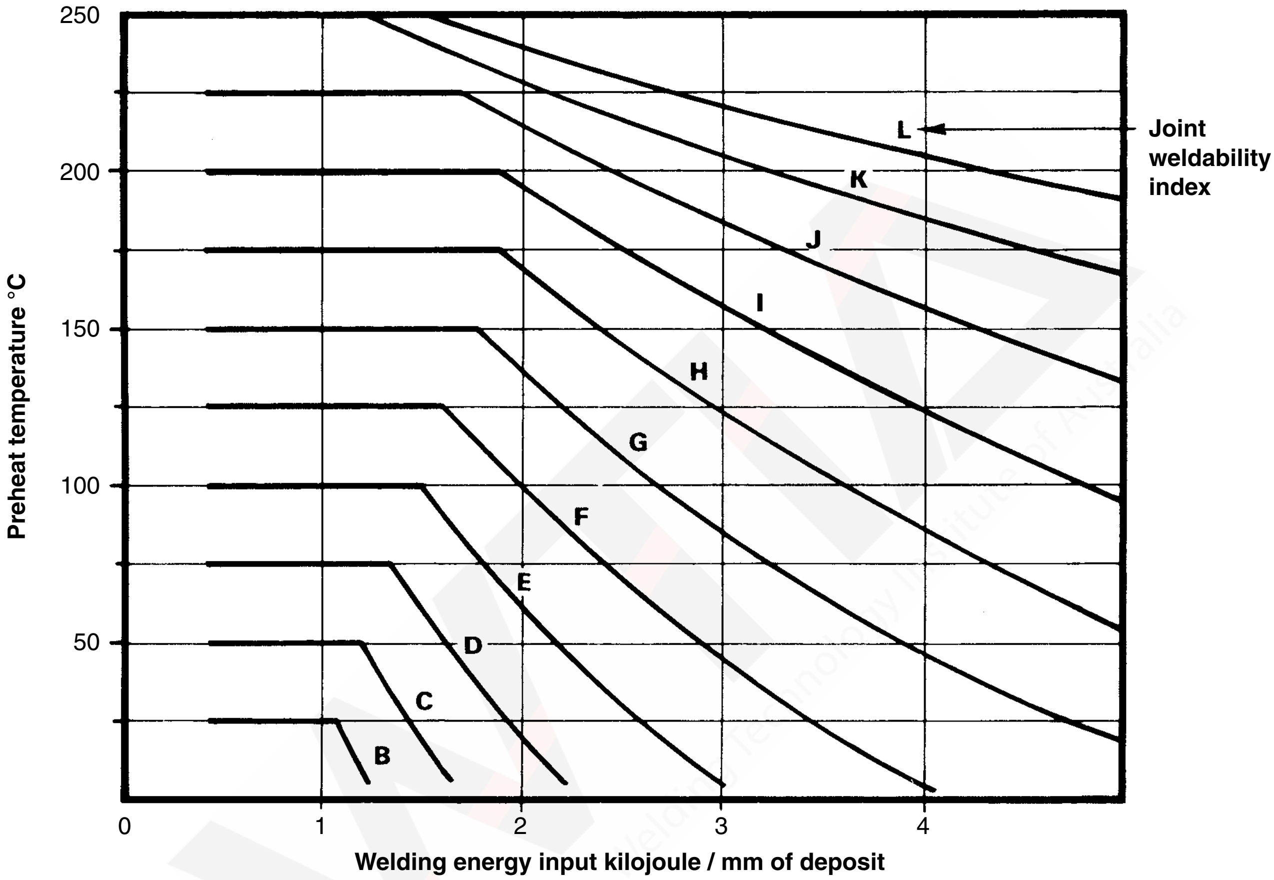


Figure 9.2 Determination of preheat requirements for hydrogen controlled consumables and processes.

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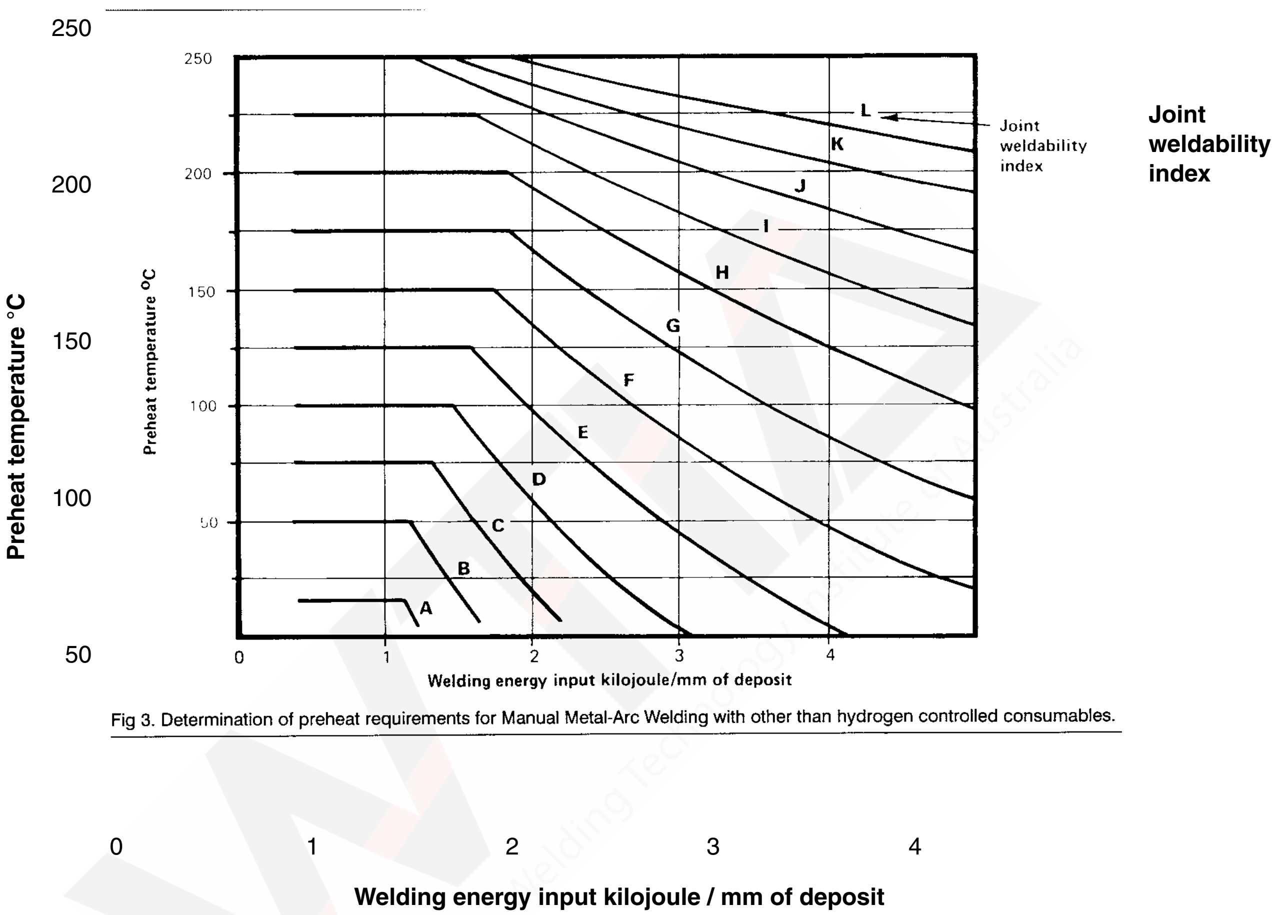

Figure 9.3 Determination of preheat requirements for non-hydrogen controlled consumables and processes.

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Table 9.1 Steel Specifications and Group Numbers

WELDABILITY

O – Any electrode type or welding process is satisfactory.
H/O – Hydrogen controlled electrodes or semi-automatic processes are recommended, but rutile or other electrodes may be used.
H – Hydrogen controlled electrodes or semi-automatic or automatic processes are essential for good welding.
SC – Slow cooling from welding or preheat temperature is recommended.
SR – Postweld heat treatment (stress relief) is suggested for high quality work, particularly where severe service conditions apply to the component.
NR – Welding is generally not recommended.
CEQ – IIW Carbon Equivalent formula (see Chapter 4).

AUSTRALIAN STANDARD SPECIFICATIONS

Spec No, Title and Grade	Steel Group Number	Weldability Notes (See above)	Cast/Product Analysis % (Values not expressed as a range are Maxima)									
			C	Mn	Si	Nb	V	Ni	Cr	Mo	Cu	CEQ
AS 1074 – 1989, Steel tubes and tubulars for ordinary service												
	3	O										
AS 1085.1 – 2002 Steel Rails												
31 & 41 kg	12	H SC SR	0.53/0.69	0.60/0.95	0.15/0.58	0.01	0.03	0.10	0.15	0.02	0.15	
50, 60 & 68 kg	12	H SC SR	0.66/0.82	0.70/1.25	0.15/0.58	0.01	0.03	0.10	0.15	0.02	0.15	
AS 1163-1991 Structural Steel Hollow Sections												
Grade C250, C250L0	1	O	0.12	0.50	0.05	0.01				0.10		0.25
Grade C350, C350L0	3	O	0.20	1.60	0.25		0.10		(Nb + V + Ti = 0.15)	0.10		0.39
Grade C450, C450L0	3	O	0.20	1.60	0.45		0.10		(Nb + V + Ti = 0.15)	0.35		0.39
AS 1442 – 1992 Hot-rolled bars and semi-finished products AS 1443 – 2004 Cold-finished bars												
Carbon Steels												
1004	1	O	0.06	0.25/0.50	0.10/0.35							
1006	1	O	0.08	0.25/0.50	0.10/0.35							
1008	1	O	0.10	0.25/0.50	0.10/0.35							
1010	1	O	0.08/0.13	0.30/0.60	0.10/0.35							
1016	2	O	0.13/0.18	0.60/0.90	0.10/0.35							
1020	2	O	0.18/0.23	0.30/0.60	0.10/0.35							
1021	3	O	0.18/0.23	0.60/0.90	0.10/0.35							
1022	3	O	0.18/0.23	0.70/1.00	0.10/0.35							

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AUSTRALIAN STANDARD SPECIFICATIONS – *continued*

Spec No, Title and Grade	Steel Group Number	Weldability Notes (See above)	Cast/Product Analysis % (Values not expressed as a range are Maxima)									
			C	Mn	Si	Nb	V	Ni	Cr	Mo	Cu	CEQ
1030	5	H/O	0.28/0.34	0.60/0.90	0.10/0.35							
1035	6	H	0.32/0.38	0.60/0.90	0.10/0.35							
X1038	8	H SC SR	0.35/0.42	0.70/1.00	0.10/0.35							
1040	8	H SC SR	0.37/0.44	0.60/0.90	0.10/0.35							
1045	9	H SC SR	0.43/0.50	0.60/0.90	0.10/0.35							
1050	10	H SC SR	0.48/0.55	0.60/0.90	0.10/0.35							
1055	11	H SC SR	0.50/0.60	0.60/0.90	0.10/0.35							
1058	10	H SC SR	0.56/0.63	0.35/0.55	0.10/0.35							
1060	12	H SC SR	0.55/0.65	0.60/0.90	0.10/0.35							
1065	12	H SC SR	0.60/0.70	0.60/0.90	0.10/0.35							
1070	12	H SC SR	0.65/0.75	0.60/0.90	0.10/0.35							
1080	12	NR	0.75/0.88	0.60/0.90	0.10/0.35							
1084	12	NR	0.80/0.93	0.60/0.90	0.10/0.35							
1095	12	NR	0.90/1.03	0.60/0.90	0.10/0.35							
Merchant Quality												
M1020	3	O	0.15/0.25	0.30/0.90	0.35							
M1030	5	H/O	0.25/0.35	0.30/0.90	0.35							
M1040	8	H SC SR	0.35/0.45	0.40/0.90	0.35							
Free-cutting												
X1112	2	NR H*	0.08/0.15	1.10/1.40	0.10							
1137.00	7	NR H*	0.32/0.39	1.35/1.65	0.10/0.35							
1144.00	10	NR H*	0.40/0.48	1.35/1.65	0.35							
1146.00	9	NR H*	0.42/0.49	0.70/1.00	0.10/0.35							
X1147	11	NR H*	0.40/0.47	1.60/1.90	0.10/0.35							
X11M47	12	NR H*	0.40/0.47	1.60/1.90	0.10/0.35		0.17/0.15		N=0.009/0.020			
1214.00	3	NR H*	0.15	0.80/1.20	0.10							
12L14	3	NR H*	0.15	0.80/1.20	0.10							

* If welding has to be carried out on free-machining steels, basic coated or specially formulated electrodes for welding sulphurised steels should be used.

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AUSTRALIAN STANDARD SPECIFICATIONS – *continued*

Spec No, Title and Grade	Steel Group Number	Weldability Notes (See above)	Cast/Product Analysis % (Values not expressed as a range are Maxima)									
			C	Mn	Si	Nb	V	Ni	Cr	Mo	Cu	CEQ
Carbon-Manganese steels												
X1315	5	H/O	0.12/0.18	1.40/1.70								
X1320	5	H/O	0.18/0.23	1.40/1.70								
X1325	6	H	0.23/0.28	1.40/1.70								
X1340	10	H SC SR	0.38/0.43	1.40/1.70								
X1345	11	H SC SR	0.43/0.48	1.40/1.70								
Carbon and Carbon-Manganese Steels with specified properties												
U3	5	H/O	0.25	1.40								
U5	8	H SC SR	0.35/0.45	0.50/1.00								
U6	9	H SC SR	0.40/0.50	0.50/1.00								
U9	6	H	0.15/0.25	1.30/1.70								
AS 1444-1996, Wrought Alloy Steels												
Standard Type												
X1320	4	H/O	0.18/0.23	1.4/1.7	0.1/0.35							
X3312	6	H	0.10/0.16	0.35/0.60	0.10/0.35			3.00/3.75	0.70/1.00			
4037	7	H	0.35/0.40	0.7/0.9	0.15/0.35				0.2/0.3			
4130	9	H SC SR	0.28/0.33	0.40/0.60				0.80/1.10	0.15/0.25			
4140	12	H SC SR	0.38/0.43	0.75/1.00				0.80/1.10	0.15/0.25			
4150	12	H SC SR	0.48/0.53	0.75/1.00	0.10/0.35			0.80/1.10	0.15/0.25			
X4317	10	H SC SR	0.15/0.20	0.40/0.60	0.10/0.35			1.40/1.70	1.50/1.80	0.25/0.35		
X4330	12	H SC SR	0.37/0.44	0.55/0.90	0.10/0.35			1.55/2.00	0.65/0.95	0.20/0.35		
4340	11	H SC SR	0.38/0.43	0.60/0.80	0.10/0.35			1.65/2.00	0.70/0.90	0.20/0.30		
4620	6	H	0.17/0.22	0.45/0.65	0.10/0.35			1.65/2.00	0.20/0.30			
5120	7	H	0.17/0.22	0.70/0.90	0.10/0.35			0.70/0.90				
5132	8	H SC SR	0.30/0.35	0.60/0.80	0.10/0.35			0.75/1.00				
5140	11	H SC SR	0.38/0.43	0.70/0.90	0.10/0.35			0.70/0.90				
5145	12	H SC SR	0.43/0.48	0.70/0.90	0.10/0.35			0.70/0.90				
5155	12	H SC SR	0.50/0.60	0.70/1.00	0.10/0.35			0.70/0.90				

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AUSTRALIAN STANDARD SPECIFICATIONS – *continued*

Spec No, Title and Grade	Steel Group Number	Weldability Notes (See above)	Cast/Product Analysis % (Values not expressed as a range are Maxima)									
			C	Mn	Si	Nb	V	Ni	Cr	Mo	Cu	CEQ
5160	12	H SC SR	0.55/0.65	0.70/1.00	0.10/0.35			0.70/0.90				
6150	11	H SC SR	0.48/0.53	0.70/0.90	0.10/0.35	0.15/0.25		0.80/1.10				
8115	4	H	0.13/0.18	0.70/0.90	0.10/0.35			0.20/0.40	0.30/0.50	0.08/0.15		
8617	6	H	0.15/0.20	0.70/0.90	0.10/0.35			0.40/0.70	0.40/0.60	0.15/0.25		
8620	6	H	0.18/0.23	0.70/0.90	0.10/0.35			0.40/0.70	0.40/0.60	0.15/0.25		
8660	12	H SC SR	0.55/0.65	0.75/1.00	0.10/0.35			0.40/0.70	0.40/0.60	0.15/0.25		
8740	9	H SC SR	0.38/0.43	0.75/1.00	0.10/0.35			0.40/0.70	0.40/0.60	0.20/0.30		
9255	12	H SC SR	0.50/0.60	0.70/1.05	1.60/2.20							
9260	12	H SC SR	0.55/0.65	0.70/1.00	1.80/2.20							
9261	12	H SC SR	0.55/0.65	0.70/1.00	1.80/2.20			0.10/0.25				
X9315	10	H SC SR	0.12/0.18	0.25/0.50	0.10/0.35			3.90/4.30	1.00/1.40	0.15/0.30		
X9931	12	H SC SR	0.27/0.35	0.45/0.70	0.10/0.35			2.30/2.80	0.50/0.80	0.45/0.65		
X9940	12	H SC SR	0.36/0.44	0.45/0.70	0.10/0.35			2.30/2.80	0.50/0.80	0.45/0.65		
Hardenability 'H' Type												
X1320H	7	H	0.17/0.24	1.30/1.80	0.10/0.35							
X3312H	8	H SC SR	0.10/0.16	0.35/0.60	0.10/0.35			3.00/3.75	0.70/1.00			
4130H	8	H SC SR	0.27/0.33	0.30/0.70	0.10/0.35			0.75/1.20	0.15/0.25			
4140H	11	H SC SR	0.37/0.44	0.65/1.10	0.10/0.35			0.75/1.20	0.15/0.25			
4150H	12	H SC SR	0.47/0.54	0.65/1.10	0.10/0.35			0.75/1.20	0.15/0.25			
X4317H	10	H SC SR	0.15/0.20	0.40/0.60	0.10/0.35			1.40/1.70	1.50/1.80	0.25/0.35		
4340H	12	H SC SR	0.37/0.44	0.55/0.90	0.10/0.35			1.55/2.00	0.65/0.95	0.20/0.30		
4620H	5	H	0.17/0.23	0.35/0.75	0.10/0.35			1.55/2.00	0.20/0.30			
5120H	6	H	0.17/0.23	0.60/1.00	0.10/0.35			0.60/1.00				
5132H	8	H SC SR	0.29/0.35	0.50/0.90	0.10/0.35			0.65/1.10				
5145H	10	H SC SR	0.42/0.49	0.60/1.00	0.10/0.35			0.60/1.00				
6150H	12	H SC SR	0.47/0.54	0.60/1.00	0.10/0.35		0.15/0.25	0.75/1.20				
8115H	6	H	0.12/0.18	0.60/0.95	0.10/0.35			0.20/0.40	0.30/0.55	0.08/0.15		
8617H	8	H SC SR	0.14/0.20	0.60/0.95	0.10/0.35			0.35/0.75	0.35/0.65	0.15/0.25		

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AUSTRALIAN STANDARD SPECIFICATIONS – *continued*

Spec No, Title and Grade	Steel Group Number	Weldability Notes (See above)	Cast/Product Analysis % (Values not expressed as a range are Maxima)									
			C	Mn	Si	Nb	V	Ni	Cr	Mo	Cu	CEQ
8620H	8	H SC SR	0.17/0.23	0.60/0.95	0.10/0.35			0.35/0.75	0.35/0.65	0.15/0.25		
86B30H	8	H SC SR	0.27/0.33	0.60/0.95	0.10/0.35			0.35/0.75	0.35/0.65	0.15/0.25		
8660H	12	H SC SR	0.55/0.65	0.70/1.05	0.10/0.35			0.35/0.75	0.35/0.65	0.15/0.25		
8740H	10	H SC SR	0.37/0.44	0.70/1.05	0.10/0.35			0.35/0.75	0.35/0.65	0.20/0.30		
9260H	10	H SC SR	0.55/0.65	0.65/1.10	1.70/2.20							
9261H	11	H SC SR	0.55/0.65	0.65/1.10	1.70/2.20			0.05/0.35				
X9315H	11	H SC SR	0.12/0.18	0.25/0.50	0.10/0.35			3.90/4.30	1.00/1.40	0.15/0.30		
Mechanical Property Requirements												
X4036	10	H SC SR	0.32/0.40	1.30/1.70	0.10/0.35					0.22/0.32		
4130	8	H SC SR	0.27/0.33	0.30/0.70	0.10/0.35				0.75/1.20	0.15/0.25		
4140	11	H SC SR	0.37/0.44	0.65/1.10	0.10/0.35				0.75/1.20	0.15/0.30		
4340	12	H SC SR	0.37/0.44	0.55/0.90	0.10/0.35			1.55/2.00	0.65/0.90	0.20/0.35		
X7039	12	H SC SR	0.35/0.43	0.40/0.65	0.10/0.35				1.40/1.80	0.15/0.25		
X7232	12	H SC SR	0.28/0.35	0.40/0.70	0.10/0.35				2.80/3.30	0.40/0.60		
X9931	12	H SC SR	0.27/0.35	0.45/0.70	0.10/0.35			2.30/2.80	0.50/0.80	0.45/0.65		
X9940	12	H SC SR	0.36/0.44	0.45/0.70	0.10/0.35			2.30/2.80	0.50/0.80	0.45/0.65		
AS 1447 – 1991 Hot-rolled spring steels												
Standard Steels												
K1070S	12	H SC SR	0.65/0.75	0.60/0.90	0.10/0.35							
K1082S	12	NR	0.78/0.90	0.60/0.90	0.10/0.35							
K1095S	12	NR	0.90/1.03	0.40/0.70	0.10/0.35							
XK5150S	12	H SC SR	0.48/0.55	0.70/1.00	0.10/0.35				0.70/0.90			
XK5155S	12	H SC SR	0.50/0.60	0.70/1.00	0.10/0.35				0.70/0.90			
XK5160S	12	H SC SR	0.55/0.65	0.70/1.00	0.10/0.35				0.70/0.90			
XK8660S	12	H SC SR	0.55/0.65	0.70/1.00	0.10/0.35			0.40/0.70	0.40/0.70	0.15/0.25		
XK9258S	12	H SC SR	0.50/0.65	0.70/1.05	1.60/2.20							
XK9261S	12	H SC SR	0.55/0.65	0.70/1.00	1.80/2.20							

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AUSTRALIAN STANDARD SPECIFICATIONS – *continued*

Spec No, Title and Grade	Steel Group Number	Weldability Notes (See above)	Cast/Product Analysis % (Values not expressed as a range are Maxima)									
			C	Mn	Si	Nb	V	Ni	Cr	Mo	Cu	CEQ
Hardenability 'H' Grades												
K5160HS	12	H SC SR	0.55/0.65	0.65/1.10	0.10/0.35				0.60/1.00			
K51B60HS	12	H SC SR	0.55/0.65	0.65/1.10	0.10/0.35				0.60/1.00			
K8660HS	12	H SC SR	0.55/0.65	0.70/1.05	0.10/0.35			0.35/0.75	0.35/0.65	0.15/0.25		
AS 1450 – 1983 Steel tubes for mechanical purposes												
Grade C200, H200	1	O	0.15						C + Mn/6 = 0.25			
Grade C250, H250, C450	4	O	0.25						C + Mn/6 = 0.42			
Grade C350, H350	5	H/O	0.22	1.60	0.50				C + Mn/6 = 0.45			
AS 1548 – 1995 Steel plates for boilers and pressure vessels												
Grade 5 – 490 N or A	5	H/O	0.24	0.90/1.70	0.60	0.01//0.07						0.48
Grade 7 – 430 R, N, T, A	4	O	0.22	0.50/1.60	0.50	0.01						0.45
Grade 7 – 460 R, N, T, A	4	O	0.20	0.90/1.70	0.60	0.01						0.45
Grade 7 – 490 R, N, T, A	5	H/O	0.22	0.90/1.70	0.60	0.01						0.48
AS 1594-2002, Hot-rolled flat products												
Analysis Grades												
HA1006*	1	O	0.08	0.40	0.03			0.35	0.30	0.10	0.35	0.29
HA1010*	1	O	0.08/0.13	0.30/0.60	0.03			0.35	0.30	0.10	0.35	0.29
HA1016*	3	O	0.12/0.18	0.60/0.90	0.03			0.35	0.30	0.10	0.35	0.39
HXA1016*	3	O	0.12/0.18	0.80/1.20	0.03			0.35	0.30	0.10	0.35	0.39
HK1042*	8	HSCSR	0.39/0.47	0.60/0.90	0.50			0.35	0.30	0.10	0.35	
HK10B55*	11	HSCSR	0.50/0.60	0.60/0.90	0.50			0.35	0.30	0.10	0.35	
HXK15B30	8	HSCSR	0.25/0.33	1.50	0.50			0.50	1.20	0.50	0.35	0.64
HK1073*	12	HSCSR	0.68/0.78	0.70/1.00	0.50			0.35	0.30	0.10	0.35	

* Cu+Ni+Cr+Mo must be less than or equal to 1%

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AUSTRALIAN STANDARD SPECIFICATIONS – *continued*

Spec No, Title and Grade	Steel Group Number	Weldability Notes (See above)	Cast/Product Analysis % (Values not expressed as a range are Maxima)									
			C	Mn	Si	Nb	V	Ni	Cr	Mo	Cu	CEQ
Formability, Structural and Weather-Resistant Grades												
HA1*	1	O	0.13	0.50	0.03	0.01**		0.15	0.15	0.05	0.15	
HA3*	1	O	0.08	0.40	0.03	0.01**		0.15	0.15	0.05	0.15	
HA4N*	1	O	0.08	0.40	0.03	0.01**		0.15	0.15	0.05	0.15	
HA200*	1	O	0.15	0.60	0.35	**		0.15	0.15	0.05	0.15	0.29
HA250, HU250*	3	O	0.20	1.20	0.35	**		0.25	0.25	0.05	0.25	0.39
HA250/1*	1	O	0.13	0.60	0.03	0.01**		0.10	0.10	0.04	0.10	0.25
HA300, HU300*	3	O	0.20	1.60	0.35	**		0.25	0.25	0.05	0.25	0.39
HA300/1, HU300/1*	3	O	0.20	1.60	0.35	**		0.25	0.25	0.05	0.25	0.39
HA350*	4	H/O	0.20	1.60	0.35		0.10***	0.25	0.25	0.05	0.25	0.44
HW350	5	H/O	0.15	1.60	0.15/0.75		0.10***	0.55	0.35/1.05	0.15/0.50	0.54	
HA400*	4	H/O	0.20	1.60	0.35		0.10***	0.25	0.25	0.05	0.25	0.44

* Cu+Ni+Mo must be less than or equal to 0.6%
** Nb+V must be less than or equal to 0.030%
*** Nb+V+Ti must be less than or equal to 0.15%

Spec No, Title and Grade	Steel Group Number	Weldability Notes (See above)	C	Mn	Si	Nb	V	Ni	Cr	Mo	Cu	CEQ
Extra Formability Grades												
XF300	3	O	0.16	1.60	0.35	*	*	0.15	0.15	0.10	0.15	0.39
XF400	4	O	0.11	1.60	0.35		0.10**	0.15	0.70	0.10	0.15	0.39
XF500	4	H/O	0.11	1.80	0.35		0.10**	0.15	0.70	0.10	0.15	0.44

* Nb+V must be less than or equal to 0.030%
** Nb+V+Ti must be less than or equal to 0.153

Spec No, Title and Grade	Steel Group Number	Weldability Notes (See above)	C	Mn	Si	Nb	V	Ni	Cr	Mo	Cu	CEQ
AS/NZS 1595 – 1998, Cold-rolled, unalloyed, steel sheet and strip												
Analysis Grades												
CA1010	1	O	0.08/0.13	0.30/0.60	0.03			0.35*	0.30	0.10	0.35	
CK10B55	11	HSCSR	0.50/0.60	0.60/0.90	0.50			0.35*	0.30	0.10	0.35	
CK1073	12	HSCSR	0.68/0.78	0.70/1.00	0.50			0.35*	0.30	0.10	0.35	

* Cu+Ni+Cr+Mo must be less than or equal to 1.00%

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AUSTRALIAN STANDARD SPECIFICATIONS – *continued*

Spec No, Title and Grade	Steel Group Number	Weldability Notes (See above)	Cast/Product Analysis % (Values not expressed as a range are Maxima)									
			C	Mn	Si	Nb	V	Ni	Cr	Mo	Cu	CEQ
Hardness, Formability and Strength Grades												
CA85T	1	O	0.15	0.60								
CA70T	1	O	0.15	0.60								
CA60T	1	O	0.15	0.60								
CA50T	1	O	0.15	0.60								
CA1	1	O	0.12	0.50								
CA2	1	O	0.10	0.45								
CA3	1	O	0.08	0.40								
CA4	1	O	0.08	0.40								
CA5SN*	1	O	0.02	0.30								
CA220	1	O	0.08	0.70								
CA260	1	O	0.09	0.70								
CA350**	2	O	0.11	1.60								
CA500	1	O	0.12	0.50								
CW300	7	H	0.15	1.60	0.15/0.75			0.55	0.35/1.05	0.15/0.50		

* Ti+Nb+V should be less than 0.3%
** Ti+Nb+V must be less than or equal to 0.15%

Spec No, Title and Grade	Steel Group Number	Weldability Notes (See above)	C	Mn	Si	Nb	V	Ni	Cr	Mo	Cu	CEQ
AS/NZS 3678 – 1996, Structural steels – Hot-rolled plates, floorplate and slabs												
Mechanical Property Grades												
200	1	O	0.15	0.60	0.35			0.5*	0.30	0.10	0.40	0.25
250, 250L15	4	O	0.22	1.70	0.55			0.5*	0.30	0.10	0.40	0.44
300, 300L15	4	O	0.22	1.70	0.55			0.5*	0.30	0.10	0.40	0.44
350, 350L15	5	H/O	0.22	1.70	0.55		0.10***	0.5*	0.30	0.35	0.40	0.48
400, 400L15	5	H/O	0.22	1.70	0.55		0.10***	0.5*	0.30	0.35	0.40	0.48
450,450L15	5	H/O	0.22	1.80	0.55		0.10***	0.50	0.30	0.35	0.60	0.48
WR350, WR350L0	5	H/O	0.14	1.70	0.15/0.75		0.10***	0.55	0.35/1.05	0.10	0.15/0.50	

* Cr+Ni+Cu+Mo must be less than or equal to 1.00%
** Nb+V must be less than or equal to 0.03%
*** Nb+Ti must be less than or equal to 0.03%

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AUSTRALIAN STANDARD SPECIFICATIONS – *continued*

Spec No, Title and Grade	Steel Group Number	Weldability Notes (See above)	Cast/Product Analysis % (Values not expressed as a range are Maxima)									
			C	Mn	Si	Nb	V	Ni	Cr	Mo	Cu	CEQ
Analysis Grades												
A1006	1	O	0.08	0.40	0.03			0.50	0.30*	0.10	0.40	
A1010	1	O	0.08/0.13	0.30/0.60	0.03			0.50	0.30*	0.10	0.40	
K1042	8	HSCSR	0.39/0.47	0.60/0.90	0.50			0.50	0.30*	0.10	0.40	
XK1016	4	O	0.12/0.18	0.80/1.20	0.50			0.50	0.30*	0.10	0.40	
XK1515	4	O	0.12/0.18	1.20/1.50	0.50			0.50	0.30*	0.10	0.40	
			* Cu+Ni+Cr+Mo must be less than or equal to 1.00%									
AS/NZS 3679.1 – 1990, Structural Steel, Part 1: Hot-rolled bars and sections												
Grade 250	4	O	0.25		0.40	0.02***	0.03*	0.50	0.30	0.10	0.50	0.43
Grade 250L0, 250L15	4	O	0.20	1.50	0.40	0.02***	0.03*	0.50	0.30	0.10	0.50	0.42
Grade 300, 300L0, 300L15	5	H/O	0.25	1.60	0.50	0.02***	0.03*	0.50	0.30	0.10	0.50	0.44
Grade 350, 350L0, 350L15 **	5	H/O	0.22	1.60	0.50		*	0.50	0.30	0.10	0.50	0.45
Grade 400, 400L0, 400L15 **	5	H/O	0.22	1.70	0.50		*	0.50	0.30	0.10	0.50	0.48
			:Total of micro-alloying elements must be less than or equal to 0.15% * Cu+Ni+Cr+Mo must not exceed 1.00% ** Nb+V+Ti must not exceed 0.15%, *** Nb+V must not exceed 0.030%									
AS/NZS 4671 – 2001, Steel reinforcing materials												
250N	4	H/O	0.22									0.43
500L	3	H	0.22									0.39
500N	4	H	0.22									0.44
300E	4	H/O	0.22									0.43
500E	5	H	0.22									0.49

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API STANDARD SPECIFICATIONS

Spec No, Title and Grade	Steel Group Number	Weldability Notes (See above)	Cast/Product Analysis % (Values not expressed as a range are Maxima)									
			C	Mn	Si	Nb	V	Ni	Cr	Mo	Cu	CEQ
API 5L – 1992, Specification for (seamless and welded) line pipe												
Seamless												
Grade A25 Cl I, Cl II	2	O	0.21	0.36/0.60								
Grade A	3	O	0.22	0.90								
Grade B	5	H/O	0.27	1.15								
Grade X42	5	H/O	0.29	1.25								
Cold-expanded Grades X46, X52	5	H/O	0.29	1.25								
Non-expanded Grades X46, X52	5	H/O	0.31	1.35								
Grades X56, X60	5	H/O	0.26	1.35								
API 5L – 1992, Specification for (seamless and welded) line pipe												
Welded												
Grade A25 Cl I, Cl II	2	O	0.21	0.30/0.60								
Grade A	3	O	0.21	0.90								
Grade B	4	O	0.26	1.15								
Grade X42	5	H/O	0.28	1.25								
Cold-expanded Grades X46, X52	5	H/O	0.28	1.25								
Non-expanded Grades X46, X52	5	H/O	0.30	1.35								
Grades X56, X60	5	H/O	0.26	1.35								
Grade X65	5	H/O	0.26	1.40								
Grade X70	5	H/O	0.23	1.60								
Grade X80	5	H/O	0.18	1.80								

SHIPPING CLASSIFICATION RULES

Spec No, Title and Grade	Steel Group Number	Weldability Notes (See above)	Cast/Product Analysis % (Values not expressed as a range are Maxima)									
			C	Mn	Si	Nb	V	Ni	Cr	Mo	Cu	CEQ
Lloyds, Norske Veritas, Bureau Veritas, American Bureau of Shipping, ASTM A131M-1991, Germanische Lloyds and Nippon Kaiji Kyokai (NK)												
Grade A	4	O										
Grade B	4	O										
Grade D	4	O										
Grade E	4	O										
Grades 32 and 36	5	H/O										

ASTM STANDARD SPECIFICATIONS

Spec No, Title and Grade	Steel Group Number	Weldability Notes (See above)	C	Mn	Si	Nb	V	Ni	Cr	Mo	Cu	CEQ
ASTM A 36M-91, Structural steel plates												
To 20 mm incl.	4	O	0.25									
over 20 to 40 mm incl.	4	O	0.25	0.80/1.20								
over 40 to 65 mm incl.	4	O	0.26	0.80/1.20								
over 65 to 100 mm incl.	5	H/O	0.27	0.85/1.20								
over 100 mm	5	H/O	0.29	0.85/1.20								
ASTM A 242M-91a, High-Strength Low-Alloy Structural Steel												
Type 1	5	H/O	0.15	1.00								
ASTM A 283M-92, Low and Intermediate Tensile Strength Carbon Steel Plates												
Grade A	2	O	0.14	0.90								
Grade B	3	O	0.17	0.90								
Grade C	4	O	0.24	0.90								
Grade D	4	O	0.27	0.90								
ASTM A 284M-90, Low and Intermediate Tensile Strength Carbon-Silicon Steel Plates												
Grade C – 25 mm and under	3	O	0.24	0.90								
Over 25 to 50 mm, incl.	4	O	0.27	0.90								
Over 50 to 100 mm, incl.	4	O	0.29	0.90								
Over 100 to 200 mm, incl.	5	H/O	0.33	0.90								
Over 200 to 300 mm, incl.	6	H	0.36	0.90								
Grade D – 25 mm and under	4	O	0.27	0.90								

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ASTM STANDARD SPECIFICATIONS – *continued*

Spec No, Title and Grade	Steel Group Number	Weldability Notes (See above)	Cast/Product Analysis % (Values not expressed as a range are Maxima)									
			C	Mn	Si	Nb	V	Ni	Cr	Mo	Cu	CEQ
Over 25 to 50 mm, incl.	4	O	0.29	0.90								
Over 50 to 100 mm, incl.	5	H/O	0.31	0.90								
Over 100 to 200 mm, incl.	6	H	0.35	0.90								
ASTM A 285M-90, Pressure Vessel Plates, Carbon Steel												
Grade A	2	O	0.17	0.90								
Grade B	3	O	0.22	0.90								
Grade C	4	O	0.28	0.90								
ASTM A 516M-90, Pressure Vessel Plates, Carbon Steel												
Grade 415												
12.5 mm and under	3	O	0.21	0.60/0.90								
Over 12.5 to 50 mm incl.	4	O	0.23	0.85/1.20								
Over 50 to 100 mm incl.	5	H/O	0.25	0.85/1.20								
Over 100 to 200 mm incl.	5	H/O	0.27	0.85/1.20								
Over 200 mm	5	H/O	0.27	0.85/1.20								
Grade 450												
12.5 mm and under	4	O	0.24	0.85/1.20								
Over 12.5 to 50 mm incl.	5	H/O	0.26	0.85/1.20								
Over 50 to 100 mm incl.	5	H/O	0.28	0.85/1.20								
Over 100 to 200 mm incl.	5	H/O	0.29	0.85/1.20								
Over 200 mm	5	H/O	0.29	0.85/1.20								
ASTM A 516M-90, Pressure Vessel Plates, Carbon Steel												
Grade 485												
12.5mm and under	5	H/O	0.27	0.85/1.20								
Over 12.5 to 50 mm incl.	5	H/O	0.28	0.85/1.20								
Over 50 to 100 mm incl.	6	H	0.30	0.85/1.20								
Over 100 to 200 mm incl.	6	H	0.31	0.85/1.20								
Over 200 mm	6	H	0.31	0.85/1.20								

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ASTM STANDARD SPECIFICATIONS – *continued*

Spec No, Title and Grade	Steel Group Number	Weldability Notes (See above)	Cast/Product Analysis % (Values not expressed as a range are Maxima)									
			C	Mn	Si	Nb	V	Ni	Cr	Mo	Cu	CEQ
ASTM A 537M-91, Pressure Vessel Plates, Heat-Treated, Carbon-Manganese-Silicon Steel												
40mm and under	5	H/O	0.24	0.70/1.35								
Over 40 mm	6	H	0.24	1.00/1.60								
ASTM A 569M-91a, Steel, Carbon (0.15% max) Hot-Rolled Sheet and Strip,												
Commercial Quality	1	O	0.15	0.60								
ASTM A 572M-92a, High-Strength Low-Alloy Niobium-Vanadium Steels												
Grade 290	5	H/O	0.21	1.35			0.01/0.15					
Grade 345	5	H/O	0.23	1.35			0.01/0.15					
Grade 415	6	H	0.26	1.35			0.01/0.15					
Grade 450												
13mm and under	6	H	0.26	1.35			0.01/0.15					
ASTM A 607-92a, Steel Sheet and Strip, High Strength, Low-Alloy, Hot-Rolled and Cold-Rolled												
Class 1, Grade 45	4	O	0.22	1.35								
Class 1, Grade 50	5	H/O	0.23	1.35								
Class 1, Grade 55	5	H/O	0.25	1.35								
Class 1, Grade 60	6	H	0.26	1.50								
Class 1, Grade 65	6	H	0.26	1.50								
Class 1, Grade 70	6	H	0.26	1.65								
Class 2, Grades 50, 55	3	O	0.15	1.35								
Class 2, Grades 60, 65	4	O	0.15	1.50								
Class 2, Grade 70	4	O	0.15	1.65								
ASTM A 662M-90, Pressure Vessel Plates, Carbon-Manganese, for Moderate and Lower Temperature Service												
Grade A	3	O	0.14	0.90/1.35								
Grade B	4	O	0.19	0.85/1.50								
Grade C	5	H/O	0.20	1.00/1.60								

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ASTM STANDARD SPECIFICATIONS – *continued*

Spec No, Title and Grade	Steel Group Number	Weldability Notes (See above)	Cast/Product Analysis % (Values not expressed as a range are Maxima)									
			C	Mn	Si	Nb	V	Ni	Cr	Mo	Cu	CEQ
ASTM A 737M-87, Pressure Vessel Plates, High-Strength, Low-Alloy Steel												
Grade B	5	H/O	0.20	1.15/1.50	0.05							
Grade C	5	H/O	0.22	1.15/1.50	0.05		0.04/0.11			N=0.03		

BRITISH (BS) / EUROPEAN (EN) STANDARD SPECIFICATIONS

BS 1501-1980, Steels for Fired and Unfired Pressure Vessels-Plates												
BS 1501-161												
Grade 360	3	O	0.17	0.40/1.20								
Grade 400	4	O	0.22	0.50/1.30								
Grade 430	5	H/O	0.25	0.60/1.40								
BS EN 10028-2 : 1993, Steels for pressure purposes, Non-alloy and alloy steels with specified elevated temperature properties												
Grade P235GH	3	O	0.16	0.40/1.20								
Grade P265GH	4	O	0.20	0.50/1.40								
Grade P295GH	5	H/O	0.08/0.20	0.90/1.50								
Grade P355GH	5	H/O	0.10/0.22	1.00/1.70								
BS EN 10025:1980, Hot rolled products of non-alloy structural steels												
Grade Fe 360	3	O										
Grade Fe 430	4	O										
Grade Fe 510	5	H/O	1.60									

Changes from the previous edition:

1. The following Australian Standards are obsolete or are superseded by other Standards and as such have been deleted. AS 1204, 1205, 1302, 1446, 1835, 1836, 1750, Aus-Ten, AIS Crane Rails
2. Duplication on analysis grades is avoided by not listing the grade twice due to suffix variation.
3. All Shipbuilding Authorities grades are grouped together as variations within the group are minimal to affect the group number. Grades 32 and 36 (high tensile grades) are also listed.

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Preheat Determination for Welding Line-pipe Steels with E4110 and E4111 Electrodes

In the field of pipeline welding, special guidance for avoidance of HAZ cracking adjacent to girth welds is necessary because of the low arc energy and more severe field conditions of stovepipe welding with cellulose electrodes, which generate a hydrogen atmosphere to produce the forceful arc required for keyhole welding of the root pass during one-side girth welding. Furthermore, recent developments in pipe steels have led to the production of much lower carbon equivalent steels than the constructional steels on which the recommendations of this Technical Note are based.

This Chapter of the Technical Note has been prepared to take these matters into consideration so as to give guidance in circumstances where:

a) ambient temperatures are below 25°C;

b) pipe wall thicknesses are less than 25 mm;

c) chemical composition limits (or carbon equivalent) of the material being fabricated are known.

The guidance is expressed in the form of a maximum pipe wall not requiring preheat for butt welds between pipes of equal thickness using E4110 or E4111 electrodes. The use of higher strength cellulosic electrodes (E48XX, E55XX and E62XX) is not covered by this Chapter.

Step 1: Calculate the Carbon Equivalent using the method given in Table 2 (Case 2) in Chapter 4.

Step 2: Refers to Table 4 to determine the maximum pipe-wall not requiring preheat for the minimum ambient temperatures and arc energy under consideration.

If the Table indicates that preheat should be applied, the pipe should be heated to 25°C minimum except when the existing method given in Chapter 9 of this Note indicates a higher preheat is required. In the latter case, the appropriate preheat from Chapter 9 Steps 1 to 6 should be employed.

Additionally, avoidance of weld metal cold cracking may require additional preheat.

Controlled Multi-run Welding

Controlled multi-run welding is the basis of welding of high strength gas transmission piping with cellulose electrodes. Close control on welding sequences and timing of multi-run welds can lead to higher inter-run temperatures and reduced cooling rates. This is normally applicable to short runs of welds as in parts of small widths or in block welding techniques; relaxation in welding preheat by this means is not recommended for sections over 50 mm thick or where close control cannot be maintained.

Table 10.1 Requirements for Linepipe Steels

MAXIMUM PIPE WALL (mm) NOT REQUIRING PREHEAT – Cellulose Electrodes, for various carbon equivalents and arc energies (Q)

Q (kJ/mm)	CARBON EQUIVALENT																					Q (kJ/mm)
	.025	0.26	0.27	0.28	0.29	0.30	0.31	0.32	0.33	0.34	0.35	0.36	0.37	0.38	0.39	0.40	0.41	0.42	0.43	0.44	0.45	
0.4	24	21	19	17	15	14	13	11	10	10	9	8	7	7	6	6	5	5	4	4	4	0.4
0.5			24	22	20	18	16	15	13	12	11	10	10	9	8	8	7	6	6	5	5	0.5
0.6					24	22	20	18	16	15	14	13	12	11	10	9	9	8	7	7	6	0.6
0.7						25	23	21	19	18	16	15	14	13	12	11	10	10	9	8	8	0.7
0.8								24	22	21	19	18	16	15	14	13	12	11	10	10	9	0.8
0.9									25	23	21	20	18	17	16	15	14	13	12	11	10	0.9
1.0											24	22	21	19	18	17	15	14	13	13	12	1.0
	PIPE TEMPERATURE = –5 Deg C																					
0.4		23	20	18	16	15	13	12	11	10	9	9	8	7	7	6	6	5	5	4	4	0.4
0.5				23	21	19	17	16	14	13	12	11	10	9	9	8	7	7	6	6	5	0.5
0.6					25	23	21	19	17	16	15	14	13	12	11	10	9	9	8	7	7	0.6
0.7							25	22	21	19	17	16	15	14	13	12	11	10	10	9	8	0.7
0.8									24	22	20	19	17	16	15	14	13	12	11	10	10	0.8
0.9										25	23	21	19	18	17	16	15	14	13	12	11	0.9
1.0											25	23	22	20	19	18	16	15	14	13	12	1.0
	PIPE TEMPERATURE = 5 Deg C																					
0.4		25	22	20	18	16	14	13	12	11	10	9	8	8	7	6	6	5	5	5	4	0.4
0.5				25	23	20	18	17	15	14	13	12	11	10	9	9	8	7	7	6	6	0.5
0.6						25	22	20	19	17	16	15	13	12	11	11	10	9	8	8	7	0.6
0.7								24	22	20	19	17	16	15	14	13	12	11	10	9	9	0.7
0.8									25	23	21	20	18	17	16	15	14	13	12	11	10	0.8
0.9											24	22	21	19	18	17	15	14	13	13	12	0.9
1.0												25	23	21	20	19	17	16	15	14	13	1.0
	PIPE TEMPERATURE = 15 Deg C																					
0.4			24	21	19	17	16	14	13	12	11	10	9	8	8	7	6	6	5	5	5	0.4
0.5					24	22	20	18	16	15	14	13	12	11	10	9	8	8	7	7	6	0.5
0.6							24	22	20	18	17	15	14	13	12	11	10	10	9	8	8	0.6
0.7									23	22	20	18	17	16	14	13	12	12	11	10	9	0.7
0.8										25	23	21	19	18	17	16	14	13	12	12	11	0.8
0.9												24	22	20	19	18	16	15	14	13	12	0.9
1.0													25	23	21	20	18	17	16	15	14	1.0
	PIPE TEMPERATURE = 25 Deg C																					

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Relaxation of Recommendations

Experience with particular materials, welding processes and joint details may indicate that some relaxation can be permitted on energy input and preheat recommendations derived from Figures 9.1, 9.2 and 9.3. Where any relaxation is contemplated from these recommendations, they should be supported either by documented experience or by suitable testing. Testing is also recommended where welding conditions differ considerably from those on which the data are based.

APPENDIX A

Basis of Recommendations

A.1 In order to facilitate correlation of welding data, use has been made of the parameter, "Cooling Rate at 300°C".

A.2 The cooling rate at 300°C has been selected to avoid the onset of HAZ cold cracking while at the same time providing some limitation on the maximum HAZ hardness achieved.

A.3 Practice has shown that higher HAZ hardness can be permitted as the Carbon content or Carbon Equivalent is increased provided the Hydrogen level is reduced.

However restrictions on the maximum hardness may be necessary to achieve the desired mechanical and fractured toughness properties of the HAZ material.

A.4 The relationship between cooling rate and carbon equivalent used for non-hydrogen controlled electrodes in these recommendations is a compromise between a maximum hardness of 350HV and cracking in the CTS test. This is justified in view of the welding experience with steel Group Numbers 4 and 5.

For hydrogen controlled processes, the relationship adopted represents an increase of 60% in the maximum cooling rates adopted for other than hydrogen controlled processes. This means for the same welding energy input and preheat, the steel Group Number is increased by one, or the carbon equivalent by 0.05%.

A.5 Readers of this technical note should be aware that as the CTS test is designed to establish crack/no crack boundary conditions for a given set of welding parameters, in some circumstances the maximum HAZ hardness realised may exceed 350HV without cracking.

Similarly, whilst this technical note is largely designed to avoid the formation of HAZ hydrogen assisted cold cracking sensitive microstructures and welding conditions, WTIA Technical Note 15 conversely does not aim to prevent the formation of hardened HAZs which are desirable to some extent in quench & tempered steels.

A.6 Cut-offs are applied to the curves on Figures 9.1, 9.3 and 9.3 as practice indicates these limiting values are realistic.

A.7 The recommendations given herein are aimed at the prevention of HAZ cracking by controlling the combination of welding energy input, hydrogen and preheat and do not necessarily cover other aspects of welding which may give rise to problems. The mechanical properties of some materials before and after welding could need further consideration as well as the requirement for postweld heat treatment to ensure satisfactory performance in service. These details are not dealt with in this Technical Note.

A.8 The formulae and basis for the predictive methods used by this Technical Note were published (Reference 7).

A.9 These recommendations do not over-ride the users obligation to demonstrate the suitability of the proposed welding procedure in accordance with good practice and the weld procedure qualification requirements of application Standards, Codes and specifications.

Appendix B

Hydrogen Levels

The quantity of hydrogen present in weld metal is crucial in determining the risk of "Hydrogen Cracking".

The Technical Note addresses the hydrogen level in weld metal by adopting the hydrogen levels in Australian (and ISO) Standards for consumable manufacture; ie:

AS/NZS 1553.1	Manual metal arc electrodes (low carbon).
AS/NZS 1553.2	Manual metal arc electrodes (low & intermediate alloy).
AS 2203.1	Flux cored electrodes.
AS 1858.2	Submerged arc (low and intermediate alloy steel).

The Effect of Hydrogen Potential on Group Numbers.

Weld Metal Hydrogen Level	Lowering of Group No by
≥ 15 ml/100 g of hydrogen	0
≤ 15 ml/100 g of hydrogen	1

It is not the intention to extend the hydrogen level to <10 ml/100g of deposited weld metal at this stage although standards allow for such levels. The Technical Expert Group reviewing the Technical Note have indicated that further work is required to quantify any benefits to be gained and additionally consider that levels below 5 ml/100 g may be unrealistic, for Australian conditions, bearing in mind the considerable influence of atmospheric situations (see References 8 to 11), and the difficulty in handling consumables to maintain these levels.

Determination of hydrogen in weld metal is specified in AS 3752, 'Diffusible Hydrogen Determination in Ferritic Weld Metal'. This standard covers MMAW, SAW, GMAW and FCAW processes.

The consumable manufacturers are responsible for specifying on the packaging, the level of hydrogen in their product and the necessary instructions to achieve these levels in practice.

Appendix C

The Affects of Sulphur and Boron on Preheat requirements.

C.1 Sulphur

The possible increase in susceptibility of steels to HAZ cold cracking with reduction in Sulphur levels is a complex subject on which there is no clear evidence of its effect. While some work has tended to indicate a causal relationship, other work has not substantiated this (Reference 12).

The concept has been linked to the number of inclusions present in the steel and hence cannot be related necessarily to the percentage of Sulphur in the steel. The presence of other potential hydrogen sinks in the vicinity of the HAZ has also to be considered. If a fabricator or user has a specific concern when welding low Sulphur steels, then confirmatory weld procedure tests should be considered.

C.2 Boron

The presence of Boron in steel needs to be considered as it makes the steel more hardenable. (Reference 12)

Boron is not accounted for in the IIW carbon equivalent formula used in this Technical Note but it is in the Japanese Pcm formula.

$$P_{cm} = C + \frac{Mn+Cr+Cu}{20} + \frac{Si}{30} + \frac{V}{10} + \frac{Mo}{15} + \frac{Ni}{60} + 5B$$

The value of the Boron factor is large, because Boron can be a potent alloying element only added to steels in small quantities, but should be regarded with some caution, because its use depends on the Boron being in an active state.

Note! Research shows that a value of 10 may be nearer to the true value for active Boron.

The position of Boron with respect to weld metal microstructure is rather more complex, because the toughness of weld metal (without hydrogen present) does not depend on hardness in the same way as does (HAZ) toughness. A tough weld metal microstructure appears to be better able to resist hydrogen cracking than one which has brittle fracture tendancy.

Appendix D

Alternative Methods for Calculating Welding Energy Input

This Appendix provides the reader with alternative methods to calculate welding energy input by using nomographs where a calculator is not available (section D.1) and also from fillet weld sizes when MMAW consumables have been used. This latter method is not recommended where accuracy of work is required but is suitable for use as a quick checking method.

D.1 Figures D1 & D2 are nomographs for calculating the heat input, and are suited for the automatic and semi automatic processes.

The process of using the nomographs is self evident and involves readings being taken for arc voltage, welding current, and welding speed in mm/minute.

D.2 Figures D3 to D5 provide a method to calculate heat input for welding, where there is a measurement taken for run-out length from the electrode being used. (The run-out ratio is established by measuring the length of the electrode in (mm) used to make the weld and dividing it by the weld metal deposit length in (mm).

The three graphs apply to the following 3 groups of Electrodes.

(a) Non Iron Powder Electrodes.
(b) Low Iron Powder Electrodes.
(c) Medium Iron Powder Electrodes.

D.3 Figure D6 is a method of estimating heat input directly from the single run fillet size for all positions of welding and for a range of electrode classifications.

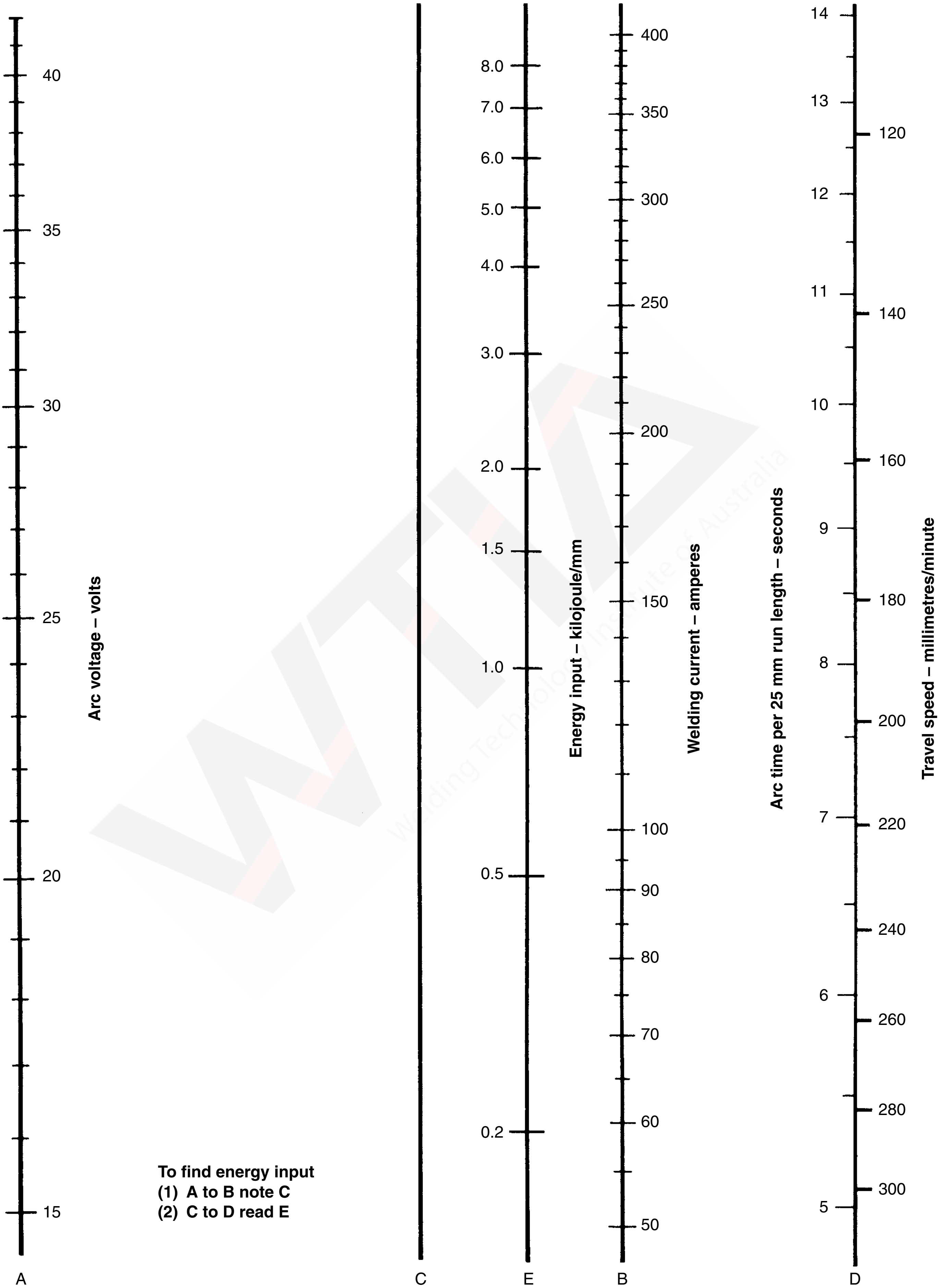

Figure D1 Welding energy input and arc voltage, current and speed for manual and automatic processes in range 60-400 amps.

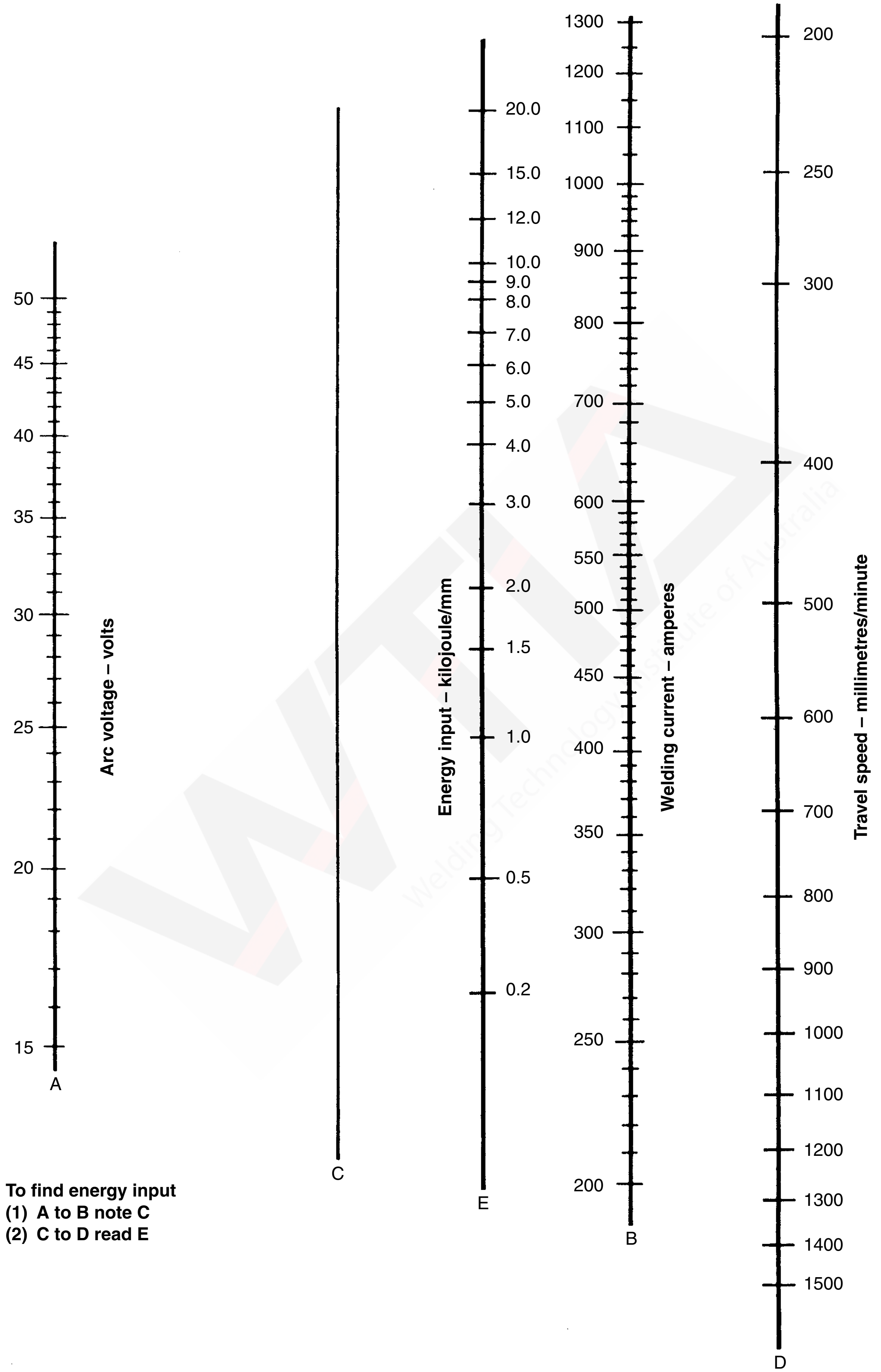

Figure D2 Welding energy input and arc voltage, current and speed for semi-automatic and automatic processes in range 200-1200 amps.

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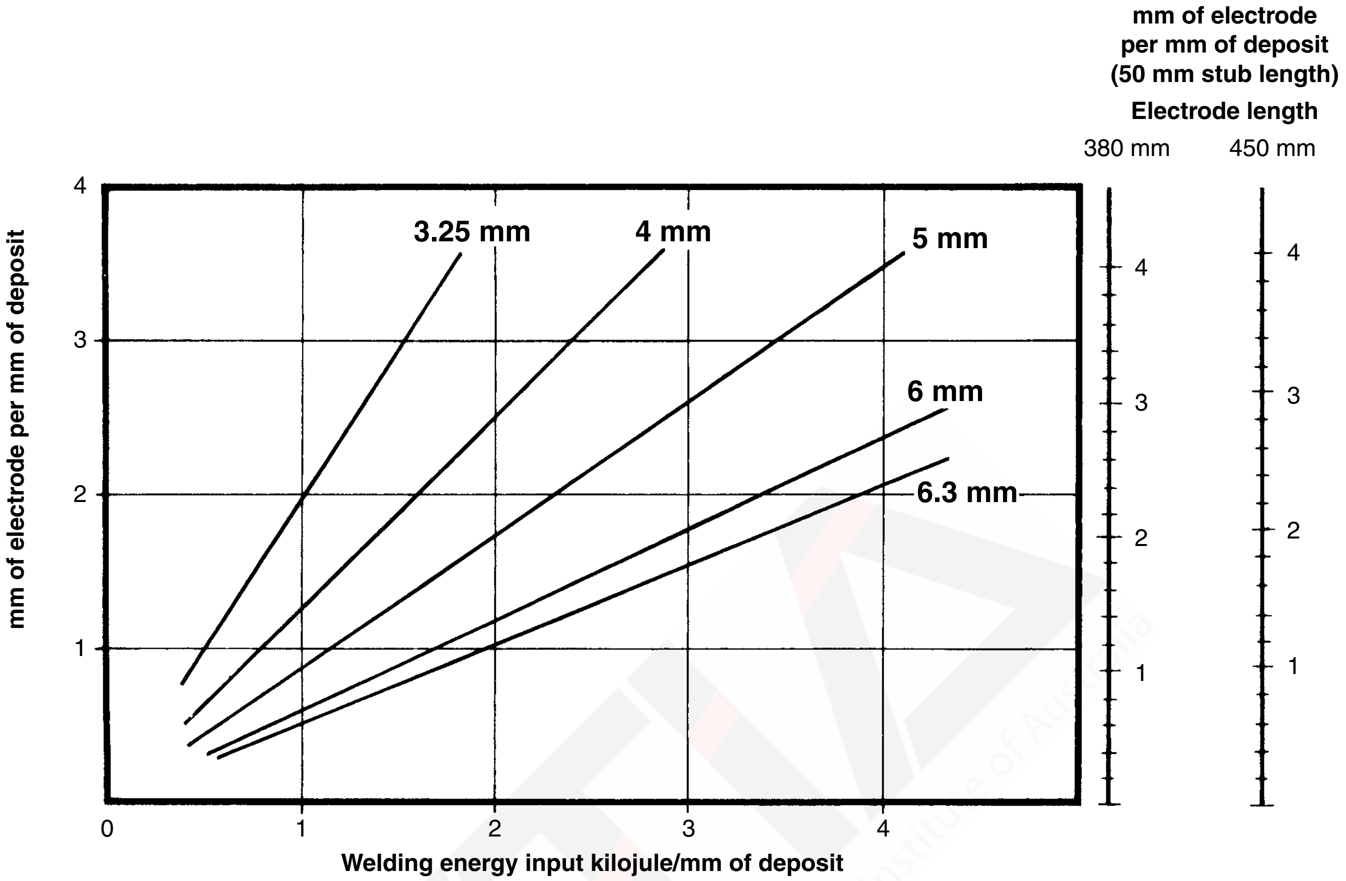


Figure D3 Welding energy input and ratio of length of electrode melted and length of deposit – for non-iron powder electrodes (EXX10, EXX11, EXX12, EXX13, EXX15, EXX16 and EXX20).

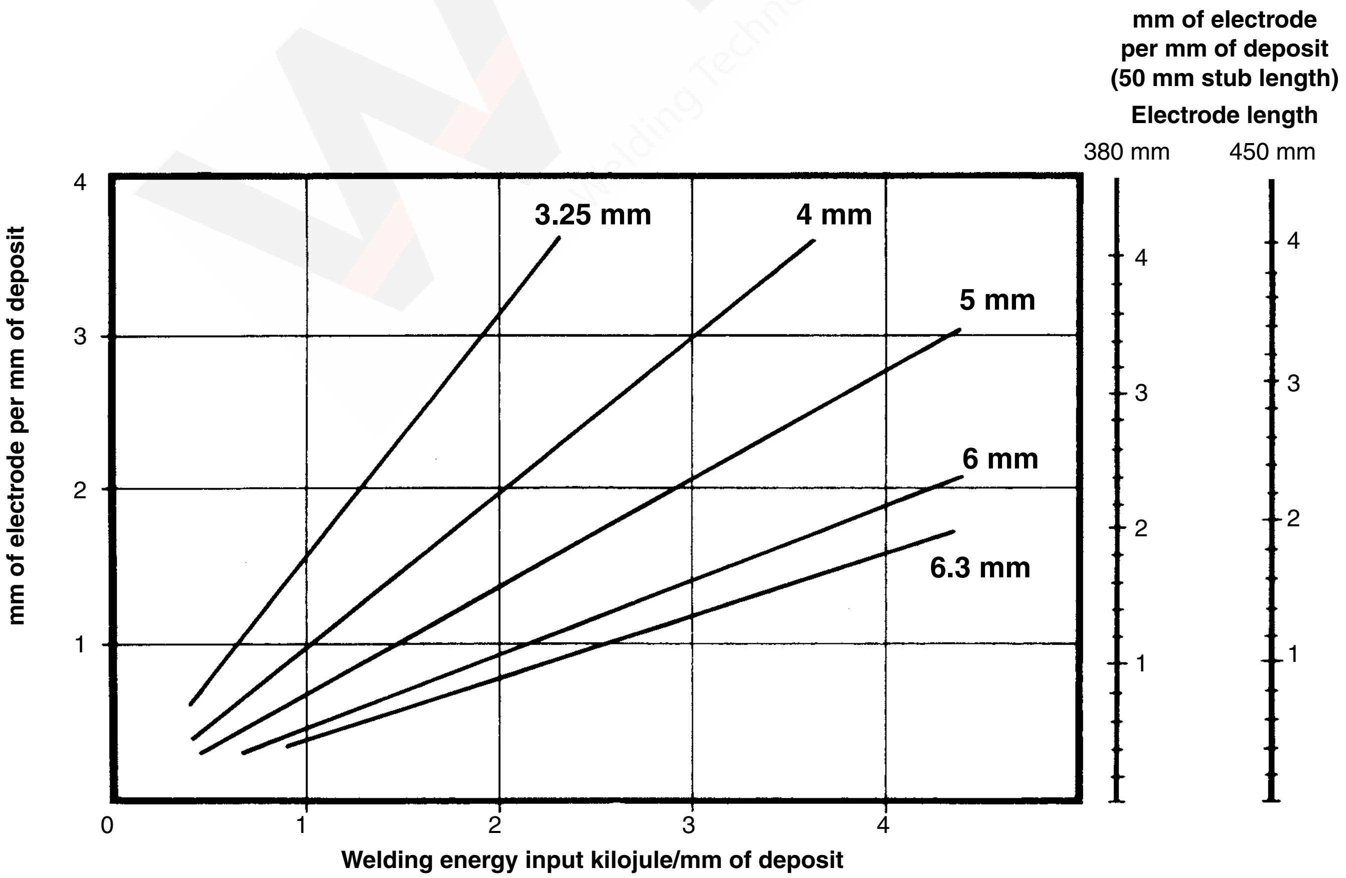


Figure D4 Welding energy input and ratio of length of electrode melted and length of deposit – for low iron powder electrodes (EXX14, EXX18).

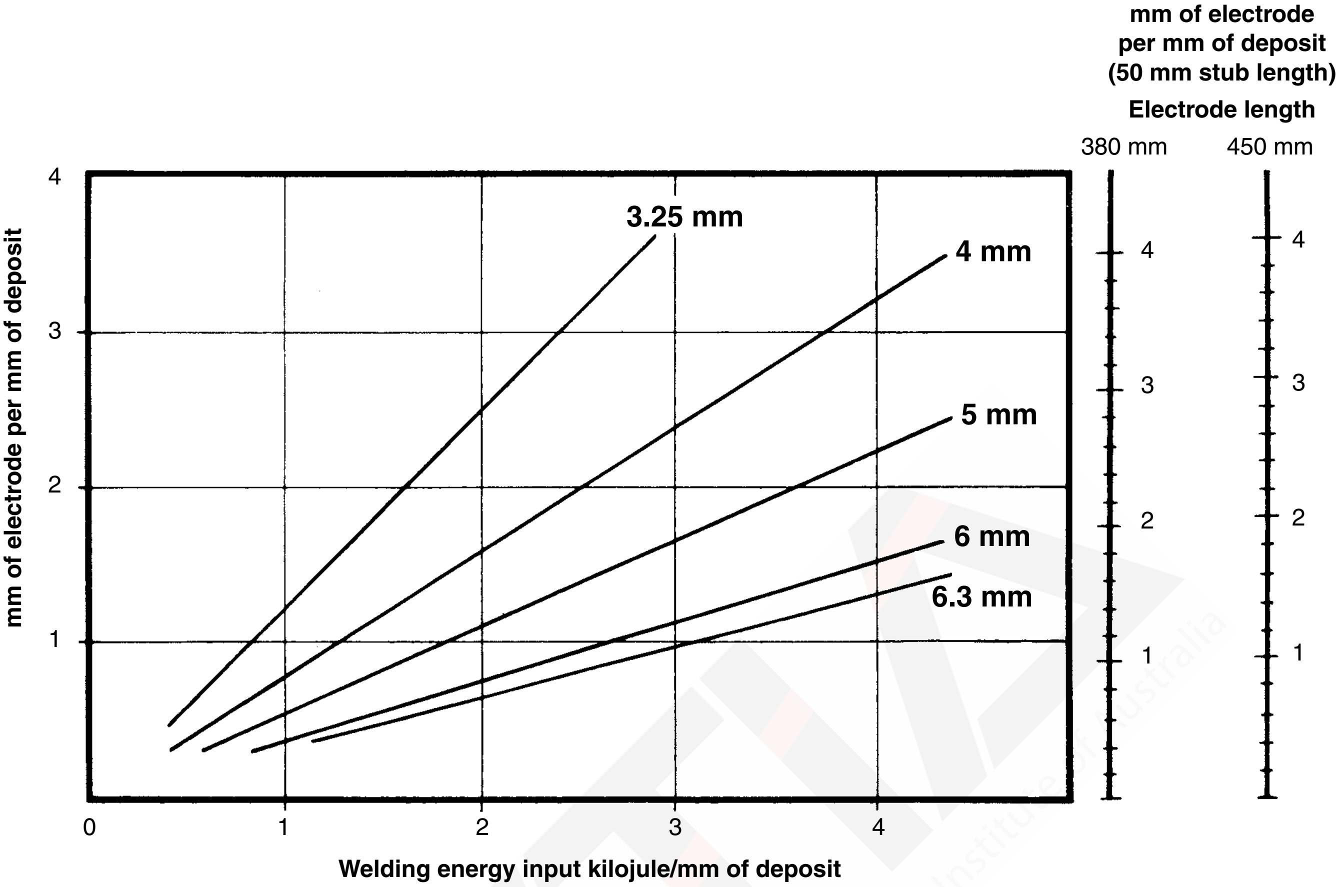
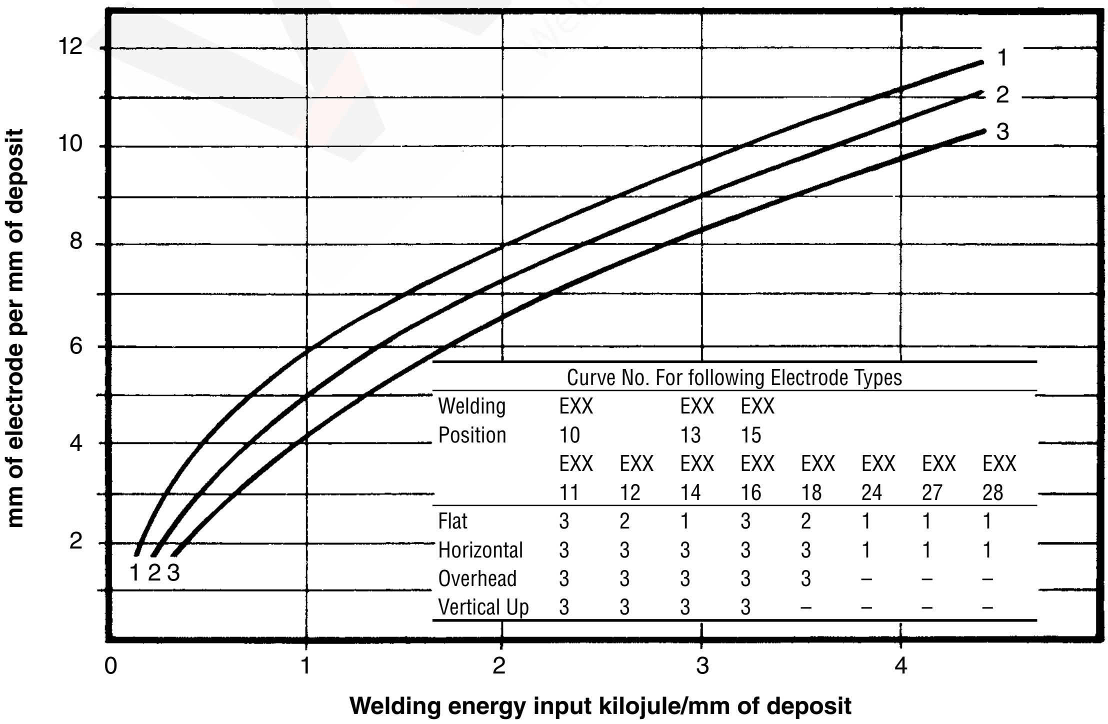


Figure D5 Welding energy input and ratio of length of electrode melted and length of deposit – for medium iron powder electrodes (EXX24, EXX27, EXX28).



Welding Position	Curve No. For following Electrode Types							
	EXX 10		EXX 13	EXX 15				
	EXX 11	EXX 12	EXX 14	EXX 16	EXX 18	EXX 24	EXX 27	EXX 28
Flat	3	2	1	3	2	1	1	1
Horizontal	3	3	3	3	3	1	1	1
Overhead	3	3	3	3	3	–	–	–
Vertical Up	3	3	3	3	–	–	–	–

Figure D6 Welding energy input and leg length of single run fillet welds.

Appendix E

References

Section 1: Standards

AS/NZS 1553.1 Covered electrodes for welding. Part 1: Low carbon steel electrodes for manual metal-arc welding of carbon and carbon-manganese steels.

AS/NZS1553.2 Covered electrodes for welding. Part 2: Low and intermediate alloy steel electrodes for manual metal arc welding of carbon steels and low and intermediate alloy steels.

AS/NZS1554.1 Structural Steel Welding Part 1: Welding of steel structures.

AS 1858.1 'Electrodes and fluxes for submerged arc welding. Part 1: Carbon and carbon-manganese steels.

AS 1858.2 'Electrodes and fluxes for submerged arc welding. Part 2: Low and intermediate alloy steels.

AS 2203.1 Cored electrodes for arc welding. Part 1: Ferritic steel electrodes

AS/NZS 2717.1 Welding – Electrodes-Gas metal-arc. Part 1: Ferritic steel electrodes.

AS 2812 Welding, brazing and cutting of metals – Glossary of terms

AS ISO 13916 Welding – Guide on the measurement of preheating temperature, interpass temperature and preheat maintenance temperature.

ISO17642-2 Destructive tests on welds in metallic materials – Cold cracking tests for weldments – Arc welding processe- Part 2: Self-restraint tests.

Section 2: Cited Documents

1. Wade J.B. The basis and background of Technical Note 1 on the Weldability of Steels. AWRA/AWI Seminar, Welding Procedures for Steel, May 1974
2. Pitrun M., Nolan D. and Dunne D. Diffusible hydrogen content in rutile flux-cored arc welds as a function of the welding parameters. IIW Doc No. IX-2064-03
3. Dickehut G. and Hotz U. Effect of climatic conditions on diffusible hydrogen content in weld metal. AWS Welding Journal, Welding Research Supplement, Jan.1991.
4. Cannon B. Influence of spatter release fluids on diffusible hydrogen levels in GMAW welds, Australasian Welding Journal, Vol 48, 4th Quarter 2003.
5. Pargeter R.J. Evaluation of necessary delay before inspection for hydrogen cracks. AWS Welding Journal, Welding Research Supplement, Nov. 2003

Section 3: Recommended Reading

Iterrante C.G. and Pressouyre G.M. Current solutions to hydrogen problems in steels. ASM Int. Conf., 1982.

Boothby P.J., "Predicting Hardness in Steel HAZs", Metal Construction, June 1985

Bailey N., Coe F.R., Gooch T.G., Hart P.H.M., Jenkins N. and Pargeter R.J. Welding steels without hydrogen cracking. Abington Publishing, 1989

Fletcher L. and Walters C. A review of the WTIA Technical Note 1 " The Weldability of Steels ", WTIA Annual Conference, Sept. 1990

Symonds H. Weld metal hydrogen – A review of its determination and other control aspects for the 1990s Australian Welding Journal, Vol. 35, No. 3, 1990.

Vuik J. An update of the state-of-the-art of weld metal hydrogen cracking. IIW Doc No. IXJ-175-92

Nolan D. and Pitrun M. Diffusible hydrogen testing in Australia. IIW Doc No. IX-2065-03

Expert Technology Tools

These Technical Note, Management System and other Expert Technology Tools may be obtained from the WTIA. Technical advice, training, consultancy and assistance with the implementation of Management Systems is also available through the WTIA's OzWeld Technology Support Centres Network and School of Welding Technology.

WTIA – PO Box 6165
Silverwater NSW 1811 Australia
Phone: +61 (0) 2 9748 4443
Fax: +61 (0) 2 9748 2858
Email: info@wtia.com.au

Visit our Internet site at http://www.wtia.com.au

WTIA Technical Notes

TN 1-06 – The Weldability of Steels

Gives guidance on the preheat and heat input conditions (run size, current, voltage) required for acceptable welds and to avoid cold cracking in a wide variety of steels. The Note is applicable to a wide range of welding processes.

TN 2-06 – Successful Welding of Aluminium

This note covers the major welding processes as they are used for the welding and repair of aluminium and its alloys. Information is given on the processes, equipment, consumables and techniques. It also provides information on the range of alloys available and briefly covers safety, quality assurance, inspection and testing, costing and alternative joining processes.

TN 3-06 – Care and Conditioning of Arc Welding Consumables

Gives the basis and details for the correct care, storage and conditioning of welding consumables to control hydrogen and to ensure high quality welding.

TN 4-06 – The Industry Guide to Hardfacing for the Control of Wear

Describes wear mechanisms and gives guidance on the selection of hardfacing consumables and processes for a wide range of applications. Includes Australian hardfacing Suppliers Compendium 1998.

TN 5-94 – Flame Cutting of Steels

Gives a wealth of practical guidance on flame cutting including detailed procedures for efficient cutting, selection of equipment and gases, practices for identifying and curing defective cutting, methods of maximising economy and other important guidance on the use of steels with flame cut surfaces.

TN 6-85 – Control of Lamellar Tearing

Describes the features and mechanisms of this important mode of failure and the means of controlling tearing through suitable design, material selection, fabrication and inspection. Acceptance standards, repair methods, specification requirements and methods of investigation are proposed. Four appendices give details on the mechanism, material factors, tests for susceptibility and the important question of restraint.

TN 7-04 – Health and Safety in Welding

Provides information on all aspects of health and safety in welding and cutting. Designed to provide this information in such a way that it is readily useable for instruction in the shop and to provide guidance to management. Recommendations are given for safe procedures to be adopted in a wide variety of situations found in welding fabrication.

TN 8-79 – Economic Design of Weldments

Principles and guidance are given on methods and procedures for optimising design of weldments and welded joints and connections to maximise economy in welding fabrication. Factors influencing the overall cost of weldments which need to be considered at the design stage are discussed.

TN 9-79 – Welding Rate in Arc Welding Processes: Part 1 MMAW

Gives practical guidance and information on the selection of welding conditions to improve productivity during manual metal arc welding (MMAW). Graphs are provided showing rates as a function of weld size. The graphs enable a direct comparison of different types of welding electrodes when used for butt and fillet welds in various welding positions.

TN10-02 – Fracture Mechanics

Provides theory and gives practical guidance for the design and fabrication of structures, planning of maintenance and assessment of the likelihood of brittle or ductile initiation from flaws in ferrous and non-ferrous alloys. Engineering critical assessment case histories are discussed.

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TN 11-04 – Commentary on the Standard AS/NZS 1554 Structural Steel Welding

The Note complements AS / NZS 1554 parts 1 to 5, by presenting background information which could not be included in the Standard. It discusses the requirements of the Standard with particular emphasis on new or revised clauses. In explaining the application of the Standard to welding in steel construction, the commentary emphasises the need to rely on the provisions of the Standard to achieve satisfactory weld quality.

TN 12-96 – Minimising Corrosion in Welded Steel Structures

Designed to provide practical guidance and information on corrosion problems associated with the welding of steel structures, together with possible solutions for minimising corrosion.

TN 13-00 – Stainless Steels for Corrosive Environments

(A Joint publication with ACA)

Provides guidance on the selection of stainless steels for different environments. Austenitic, ferritic and martensitic stainless steels are described together with the various types of corrosive attack. Aspects of welding procedure, design, cleaning and maintenance to minimise corrosion are covered.

TN 14-84 – Design and Construction of Welded Steel Bins

Written because of the widely expressed need for guidance on the design and fabrication of welded steel bulk solids containers, this Technical Note gathers relevant information on functional design, wall loads, stress analysis, design of welded joints and the fabrication, erection and inspection of steel bins. It also contains a very comprehensive reference list to assist in a further understanding of this very broad subject.

TN 15-96 – Welding and Fabrication of Quenched and Tempered Steel

Provides information on quenched and tempered steels generally available in Australia and gives guidance on welding processes, consumables and procedures and on the properties and performance of welded joints. Information is also provided on other important fabrication operations such as flame cutting, plasma cutting, shearing and forming.

TN 16-85 – Welding Stainless Steel

This Technical Note complements Technical Note Number 13 by detailing valuable information on the welding of most types of stainless steels commonly used in industry.

TN 17-86 – Automation in Arc Welding

Provides information and guidance on all the issues involved with automation in arc welding. The general principles are applicable to automation in any field.

TN 18-87 – Welding of Castings

Provides basic information on welding procedures for the welding processes used to weld and repair ferrous and non-ferrous castings. It also provides information on the range of alloys available and briefly covers non-destructive inspection, on-site heating methods and safety.

TN 19-95 – Cost Effective Quality Management for Welding

Provides guidelines on the application of the AS / NZS ISO 9000 series of Quality Standards within the welding and fabrication industries. Guidance on the writing, development and control of Welding Procedures is also given.

TN 20-04 – Repair of Steel Pipelines

Provides an outline of methods of assessment and repair to a pipeline whilst allowing continuity of supply.

TN 21-99 – Submerged Arc Welding

Provides an introduction to submerged arc welding equipment, process variables, consumables, procedures and techniques, characteristic weld defects, applications and limitations. Describes exercises to explore the range of procedures and techniques with the use of solid wire (single and multiple arcs) and provides welding practice sheets, which may be used by trainees as instruction sheets to supplement demonstrations and class work, or as self-instruction units.

TN 22-03 – Welding Electrical Safety

Provides information and guidance on welding electrical safety issues: welding equipment, the human body and the workplace.

TN 23-02 – Environmental Improvement Guidelines

Provides information and guidance on how to reduce consumption in the Welding and Fabrication industry, while reducing the impact on the environment at the same time.

TN 24-03 – Self-Assessment of Welding Management and Coordination to AS/NZS ISO 3834 and ISO 14731 (CD-ROM only)

Provides instruction and guidance to enable Australian companies to:

- Understand the aims and application of these quality standards
- Appreciate the relevance and implications of these standards
- Conduct a self-assessment of quality requirements
- Devise an action plan to meet the quality requirements
- Obtain certification to AS / NZS ISO 3834 / ISO 3834 / EN 729

The CD contains a comprehensive checklist that addresses all the elements of AS / NZS ISO 3834 for an audit or certification purpose. The CD also contains useful checklists for Welding Coordination activities and responsibilities.

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TN 28-04 – Welding Management Plan and Audit Tool for Safe Cutting and Welding at NSW Mines to MDG 25 (CD-ROM only)

Will assist mining companies to implement a Welding Management Plan (WMP) compliant with MDG 25 "Guideline for safe cutting and welding at mines" as published by the NSW Department of Mineral Resources. The ETT:

- Will assist in the development, implementation and auditing of a WMP for safe cutting and welding operations in mines
- Contains a generic WMP that can be edited and tailored to suit your purpose
- Describes the processes to be employed, the standards to be referenced and the issues to be addressed in the development of a WMP
- Contains an Audit Tool that can be used to develop risk assessment for welding and cutting
- Contains Procedures, Work Instructions and Forms/ Records for safe cutting and welding activities that can be adapted as necessary for your mine.

WTIA Management Systems

MS01-TWM-01 Total Welding Management System
Interactive CD-ROM

Welding Occupational Health, Safety & Rehabilitation Management System

MS02-OHS-01 OHS&R Managers Handbook

MS03-OHS-01 OHS&R Procedures

MS04-OHS-01 OHS&R Work Instructions

MS05-OHS-01 OHS&R Forms and Records
Four Expert Technology Tools incorporated into one Interactive CD-ROM

MS06-ENV-01 Welding Environmental Management System
Interactive CD-ROM

WTIA Pocket Guides

These handy sized Pocket Guides are designed to be used on a practical day-to-day basis by welding and other personnel.

PG01-WD-01 Weld Defects

Will assist Welders, Welding Supervisors and others in the identification and detection of defects, their common causes, methods of prevention and in their repair.

PG02-SS-01 Welding of Stainless Steel

A concise guide for Welders, Welding Supervisors to welding processes and procedures for the fabrication of stainless steel including Codes, Standards and specifications, cleaning and surface finishing, good welding practice and precautions.

Other Expert Technology Tools

Contract Review for Welding and Allied Industries *(CD-ROM only)*

Explains how to review design, construction, supply, installation and maintenance contracts in the welding industry. It has been designed for private and government organisations acting in the capacity of a client or a contractor or both.

The CD contains more than 36 checklists covering areas such as structures, pressure equipment, pipelines, non-destructive testing and protective coatings to various Australian Standards.

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