Welding Technology Institute of Australia

Research, Education, Technical Support & Information

WTIA Technical Note No. 15

Welding & Fabrication of Quenched and Tempered Steel

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

Published by the Welding Technology Institute of Australia

WTIA
ABN 69 003 696 526
Unit 3, Suite 2 9 Parramatta Road
Lidcombe NSW 2141
PO Box 6165
Silverwater NSW 1811
Tel: +61 (0)2 9748 4443
Fax: +61 (0)2 9748 2858
Email: info@wtia.com.au
Website: www.wtia.com.au

Core Partner of the Cooperative Research Centre for Welded Structures

Welding Technology Institute of Australia

The Welding Technology Institute of Australia (WTIA) is the recognised national Australian Body representing the overall interests of the “welding” industry, with its primary goal to: “assist in making Australian Industry locally and globally competitive in welding-related activities”. The Goal and Strategies within its Business Plan cover the ‘Total Life Cycle of Welded Products/Structures’.

The WTIA is a membership based, cooperative, not-for-profit, national organisation representing the Australian welding industry and is registered as a ‘Company Limited by Guarantee” under the Australian Corporations Law. WTIA is governed by a Council elected by the Divisions and Corporate Members.

Formed in 1989 through an amalgamation of the Australian Welding Institute (AWI) (founded 1929) and the Australian Welding Research Association (AWRA) (founded 1964), its key roles have been, and still are, predominantly in technology transfer, certification of personnel, education and training, provision of technical services and facilitating research and development.

Through its Council, Boards and Industry Support Groups, and Technical Panels it has representation from a tremendous range of industry, government authorities and educational institutions both locally and internationally.

Membership is offered within various categories and professional levels, presently consisting of approximately 1,400 individual members and 300 company members, whose annual subscriptions provide a significant portion of the operating costs of the organisation.

The current staff of 22 includes 13 engineer/technologists with a variety of specialist backgrounds in welding technology. This expertise is complemented by Industry Support (SMART and Technology Expert) Groups and Technical Panels with over 300 technical specialists, and by a number of WTIA voluntary Divisional Bodies in all States and Territories. Together they contribute on a significant scale to Australian Industry through its excellent network of volunteers throughout Australia and the wide cross-section of its membership from MD to welder.

The WTIA provides a very wide range of services to industry across Australia, Government and individual members. It is the body representing Australia on the International Institute of Welding, is a Core Partner of the CRC for Welded Structures, and it has a number of MOUs with kindred local and overseas bodies. It is actively involved in numerous initiatives to assist in improving the competitiveness of Australian Industry.

WTIA National Diffusion Networks Project, SMART TechNet Project and OzWeld Technology Support Centres Network

Welding technology in the broadest sense plays a major role in Australia’s well-being and is utilised by over 20,000 Australian businesses large and small with over 300,000 employees. The Welding Technology Institute of Australia (WTIA) is a significant player with industry in promoting improvements in industry through optimum use of Technology.

The Federal Industry Minister, Ian Macfarlane, announced that the WTIA has received a $2.45m grant from the AusIndustry Innovation Access Program (IAccP) – Industry. The Institute launched its new Industry Sectoral Projects (ISPs) from 1 September 2003 as part of the WTIA National Diffusion Networks Project. The Projects involve the implementation of a structured welding and joining technology demonstration and improvement program in seven Australian industry sectors over three years (2003-2006).

The sectoral strategy involves the WTIA working directly with leading Australian firms, SMEs, supply chains and technology specialists in the OzWeld Technology Support Centres (TSCs) Network to help them:

- analyse and define the key challenges, opportunities and requirements that will govern the competitiveness of Australia’s capability in each sector and identify specific areas where welding, joining and fabrication innovation and technology needs to be upgraded and transferred to improve both their own and Australia’s competitive advantage and market performance in that sector;
- demonstrate project activities and identify how the solutions can be implemented, document the activities of the demonstration projects and outcomes, disseminate activities to the wider industry and plan activities for future actions needed, including research, development, education, training, qualification and certification.
- document key Expert Technology Tools and Technical Guidance Notes for each technology/ sector application and facilitate the ongoing uptake, tailored application and skills development in each of the welding/joining/fabrication technologies identified through the program.

The new industry sectors to be tackled include ***rail, road transport, water, pressure equipment, building & construction, mining and defence.***

The new NDNP will also act as an umbrella encompassing the two other projects for which we previously received substantial Federal Government, State Government and industry funding.

The OzWeld Technology Support Centres Network will continue to support solutions to meet the needs of industry and will be expanded to 35 local and 20 overseas TSCs, all contributing appropriate and leading-edge technologies to assist all industry sectors.

The SMART TechNet Project, with its SMART Industry Groups and Industry Specific Groups (ISGs) already running in the Power Generation, Petro/Chemical, Pipelines, Alumina Processing, Inspection & Testing and Fabrication industries will continue in parallel with the new Project, with potential for interesting “cross pollination” with groups for the new Industry Sectoral Projects (ISPs) and SMART Groups.

Major benefits from this Project are overall improvement and competitiveness of Australian industry through the use of latest proven technology, economically diffused by a greatly improved network, as well as improved and expanded services to sponsor companies. The Project is believed to be the major practical strategy for rapid improvement of our “welding” businesses. The returns on investment for all parties on the WTIA OzWeld Technology Support Centres Project and SMART TechNet Project have been enormous. The return on this new National Diffusion Networks Project is expected to be even higher for parties involved.

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 at the back 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:

Elements	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:

- Contains information relevant to the welding and fabrication of a range of quenched and tempered steels used for structural and abrasion resistant purposes;
- Is intended to assist tradesmen, supervisors, inspectors, managers and engineers in understanding such steels;
- Is designed to assist students in obtaining practical and theoretical information on quenched and tempered steels;
- Is a revision of the March 1985 edition of this technical note and has been prepared using the latest literature and information available from the industry;
- Shows various applications of quenched and tempered steels in Australia;
- Has been prepared under the direction of WTIA Technical Panel 2 *Weldability of Steel* currently consisting of:

  Mr Ian Squires (Convenor) – BHP-Flat Products Division
  Mr Graham Arvidson – Department of Agriculture, Energy and Minerals
  Mr Russell Barnett – Bisalloy Steels Pty Ltd
  Mr Hayden Dagg – Tubemakers of Australia Ltd
  Mr Richard Eager – Stork Wescon Australia Pty Ltd
  Dr Ian French – CSIRO Division of Manufacturing Technology
  Mr David Hatcher – BOC Gases Australia Ltd
  Mr Peter Howard – CBI Construction Pty Ltd
  Mr Rick Kuebler – Cigweld
  Dr Robert Phillips – Materials Research Laboratories
  Mr Steve Rouse – Welding Industries of Australia
  Dr Wolfgang Scholz – NZ Welding Centre
  Mr Robert Sim – Lincoln Electric Co. (Aust.) Pty Ltd
  Dr Arch Vetters – TAPNAL

Acknowledgments

The WTIA and Panel 2 would like to thank the following individuals and organisations for their contribution to this document:

Mr Russell Barnett – Bisalloy Steels Pty Ltd
Mr Rick Kuebler – CIGWELD
Mr Steve Rouse – Welding Industries of Australia

Future Revisions

This Technical Note will be revised from time to time and comments aimed at improving its value to industry will be welcome. No extracts from this publication may be printed or published in any form without the WTIA's permission.

Disclaimer

Mr Ben Gross, Technical Manager and Editor

National Library of Australia card number and ISBN 0 909539 55 3

This page left blank intentionally.

Contents

This page left blank intentionally.

INTRODUCTION

Quenched and tempered (Q&T) low alloy steels, particularly in plate form, are being used increasingly in both structural and abrasion resistant applications. The continuing increase in usage is due partly to greater local availability since the establishment of a domestic manufacturer, and partly to a greater appreciation of the advantages these steels can offer when selected, fabricated and used correctly.

Advantages arising from the use of Q&T steels relate to lighter structures, greater load carrying capacities and improved service life of components, especially in abrasive environments.

High strength structural Q&T steels are mainly used in applications such as bridges, buildings, longwall mining roof supports, storage tanks, booms and dipper sticks, cranes, penstocks, road and rail tankers and wagons where loadings are high and weight saving is critical. For example in the transport industry, heavier payloads can be carried on lighter vehicles and in the construction industry, savings in costs can be effected in the form of lighter structures for similar loadings, lighter foundations and reduced volumes of deposited weld metal.

Abrasion resistant Q&T plate grades are used in applications involving abrasive wear to increase service life, reduce equipment down-time and thereby increase operating profitability. They are particularly useful in materials handling situations such as chutes, bins, liner plates, dump truck floors and longwall pan lines. In many abrasive wear conditions, reduction in wear rate is directly proportional to plate hardness.[1]

Welding is by far the most common means of fabrication and attachment, and may be involved in over 80% of applications of Q&T steels. Appropriate welding procedures and fabrication practices are required to ensure the full potential of these steels is realised. The current edition of the Structural Steel Welding Code AS/NZS 1554.4 provides useful rules for the welding of a wide range of welded constructions using high strength Q&T steels.

Scope

This Technical Note provides basic information on the types of Q&T steels commonly encountered in Australia, and presents general recommendations and guidance on:

a) selection of welding process;
b) care and choice of consumables;
c) welding procedures;
d) related fabrication operations such as flame cutting, shearing and forming.

Information presented also relates to the properties and performance of the welded joints, and in so doing draws heavily on the data published by Bisalloy Steels Pty Ltd and Nippon Steel Corporation.

Steels covered by this Note include a range of structural (including pressure vessel) and abrasion resistant grades, normally containing less than 3% total alloying elements (i.e. manganese + nickel + chromium + copper + molybdenum).

NOTE: *Although the general comments may also relate to other Q&T steels such as BIS 812-EMA, the HY-80/HY-100 military grades, quenched and tempered 9% Ni steels (ASTM A553) and high chromium Cr-Mo steels (ASTM A387), these steels are not considered in this Technical Note. Special requirements associated with their use would normally involve procedures, practices and consumables other than those presented herein.*

Photo 1: HMAS Collins Class Submarine, from locally manufactured Q&T material, undergoing sea trials.

return to contents

next page

Q&T Steel Specifications

3.1 High Strength Structural Plate Grades

Quenched and tempered structural steels are manufactured and supplied in Australia to meet the requirements of AS 3597 *Structural and Pressure Vessel Steel – Quenched and Tempered Plate*. These steels are recognised by the Structural Steel Welding Code AS/NZS 1554.4 and the Unfired Pressure Vessels Code AS 1210. The latter code recognises AS 3597 Grade 700PV and a number of the grades of these types of steel as acceptable materials falling within the scope of the Code. At the date of publication of this Technical Note (1996), these steels were omitted from the general provisions of the SAA Steel Structures Code AS 4100 due to its current exclusion of steel for which the value of yield stress used in design exceeds 450 MPa (i.e: the vast majority of commercially useful Q&T steel plate grades). However, a program of testing to fully qualify AS 3597 Q&T steels to AS 4100 is currently in progress. Whilst testing on stub and column sections is complete, work particularly relating to fatigue performance, thermal effects and fire resistance remains. In addition, both AS 4100 and AS 1210 allow the use of alternative materials when their acceptability has been adequately demonstrated to the relevant statutory authority or approval committee.

A number of national and international Standards exist overseas covering the manufacture and supply of a range of high strength structural Q&T plate grades, and building and fabrication codes embrace design in, and application of, these steels. A number of these standards are referenced in summary form in Table 1.

In Australia, proprietary grades of Q&T steels are usually manufactured and supplied in accordance with AS 3597. In Japan and Europe transactions involving steel grades of the HT70 class with tensile strengths above 685 MPa are usually executed in accordance with proprietary specifications and specific purchase requirements.

In North America the ASTM A514/A517 specifications are generally adhered to, with particular steel manufacturers aligning their proprietary grades to one or more of the fifteen grades in these specifications. In fact the mechanical properties specified in ASTM A514/A517 tend to form the basis of all of the commercially important, proprietary steels of the HT80 class.

Photo 2: Northern Territory Parliament House – extensive use was made of AS 3597 grade 600 in the columns and transfer beams due to predicted cyclonic wind loadings

return to contents next page

Table 1 – Summary of Standards Related to High Strength Q&T Steels

Standard	Grade	Plate Thickness Range (mm)	Tensile Properties			Charpy Impact Properties
			0.2% PS (MPa) min.	TS (MPa)	% El min.	
AS 3597	500	≥5 ≤100	500	590-730	20	80 J min @ –20°C
	600	≥5 ≤100	600	690-830	20	75 J min @ –20°C
	700	≤5 >5 ≤65 >65 <110	650 690 620	750-900 790-900 720-900	18 18 16	40 J min @ –20°C
	700PV	≤5 >5 ≤65 >65 <110	650 690 620	750-900 790-930 720-900	18 18 16	0.38 mm min lateral expansion at test temp ≤ 0°C
ISO 4950/3	E420	≤50 >50 ≤70	420 400	530-680	18 18	All grades 40 J min @ –20°C 27J min @ –50°C
	E460	≤50 >50 ≤70	460 440	570-720	17 17	
	E500	≤50 >50 ≤70	500 480	610-770	16 16	
	E550	≤50 >50 ≤70	550 530	670-830	16 16	
	E620	≤50 >50 ≤70	620 600	720-890	15 15	
	E690	≤50 >50 ≤70	690 670	770-940	14 14	
ASTM A514	All	<64 ≥64 ≤152	690 620	760-895 690-895	18 16	Subject to negotiation
ASTM A517	All	<65 ≥65 ≤150	690 620	795-930 725-930	16 14	0.38 mm min lateral expansion at test temp ≤ 0°C
BS 7613	S390J6Q S450J6Q	≤40 ≤16 >16 ≤25 >25 ≤40	390 450 430 415	490-640 550-700	18 17	27 J min @ –60°C 27 J min @ –60°C
NIPPON KAIJI KYOKAI	KHT 60 KHT 70 KHT 80	≤40 ≤40 ≤40	450 615 685	590-705 685-825 785-930	16 14 13	All grades 27 J min @ –20°C

Notes

1. PS = 0.2% Proof Stress
2. TS = Tensile Stress
3. El = Elongation on 50mm gauge length
4. All Charpy impact properties are from longitudinal tests. Lateral expansion tests are transverse tests
5. NIPPON KAIJI KYOKAI = Japan Register of Shipping

Photo 3: Transportable Road Tanker Manufactured to AS 1210 from AS 3597 grade 700PV

The ANSI/AWS *Structural Welding Code – Steel*, D1.1, provides general guidance for the design of welded connections, welding techniques and workmanship, the qualification and inspection of welds and design of new buildings, bridges and tubular structures. Steels to either ASTM A514 or A517 are approved base metals under the code provisions relating to building, bridges and tubular structures (excluding pressure vessels and pressure piping).

Complementary codes which facilitate design in and fabrication of high strength Q&T steels include:

a) American Institute of Steel Construction Specification for the Design, Fabrication and Erection of Structural Steel for Buildings;
b) American Association of State Highway and Transportation Officials, Standard Specifications for Highway Bridges;
c) American Railway Engineering Association Specifications for Steel Railway Bridges.

"Contemporary" weldable high strength structural Q&T steels must be carefully distinguished from "conventional" Q&T grades due to their alloy design. "Conventional" Q&T steels are characterised by higher alloy contents with typical CE_{IIW} values > 0.55 whereas many of the "contemporary" Q&T products have typical CE_{IIW} values of 0.38 – 0.55 (depending on thickness). These leaner chemistry steels exhibit the same or better strength and impact properties and improved fabrication/welding characteristics. The properties are enhanced further by a combination of "clean" steel processing, carefully selected small amounts of alloying/ microalloying elements and special rolling and Q&T heat treatment methods.

3.2 Abrasion Resistant Plate Grades

Abrasion resistant Q&T plate grades are characterised by an almost universal absence of national standards covering their manufacture and supply. They are usually marketed under proprietary trade names (e.g. Bisplate 360) and their supply is controlled by steel manufacturer's specifications and particular customer requirements.

Occasionally the chemical compositions of abrasion resistant plates are specified by reference to an existing structural steel specification (e.g. ASTM A514 Grade B), but the mechanical properties of that specification are waived and replaced by a hardness specification only (e.g. 360-400 HB 3000/10).

The only unifying factor amongst the numerous proprietary specifications for abrasion resistant Q&T plate is the reliance on surface hardness, as measured by the Brinell hardness test method, as the means of specifying the product. Commonly, minimum or nominal hardness levels are chosen from the following preferred values (expressed as HB or HB 3000/10):

a) 250
b) 320
c) 360
d) 400
e) 500

In any particular application, wear may be due to a combination of causes including abrasion, erosion, impact, corrosion. The benefits in quantitative terms to be gained from using abrasion resistant plates will vary with particular environmental and service conditions.

These parameters would include:

a) particle size of the abrasive medium;
b) relative hardness of the abrasive medium and the wearing surface;
c) ambient temperature;
d) velocity and impingement angle of the abrasive medium in relation to the wearing surface.[2]

In selecting the correct grade of abrasion resistant plate, consideration should also be given to the required fabrication operations, particularly in respect to ease of drilling and forming.

Photo 4: High Strength/Wear Resistant Steels used in Typical Mining Operation

return to contents next page

This page left blank intentionally.

Manufacture of Q&T Steels

4.1 Production of Q&T Steels

After a controlled rolling on a conventional plate mill, modern Q&T plate grades are then subject to a heat treatment cycle as follows:

a) Plates are first heated to austenitising temperatures (approximately 880 – 950°C) and soaked at that temperature for the required period of time depending on plate thickness and chemical composition.

b) After conditioning in the furnace, plates are quenched with water (usually sprayed simultaneously onto both plate surfaces) in a roller pressure quench or platen quench unit until cold. Roller pressure quenches offer advantages over platen quenches in terms of metallurgical properties and product shape. The as-quenched condition generally represents maximum strength and hardness coupled with comparatively low ductility.

c) After hardening by quenching, plates are reheated in a tempering furnace, to a temperature dependent on the desired combination of properties, for periods of time again related to plate thickness and chemical composition.

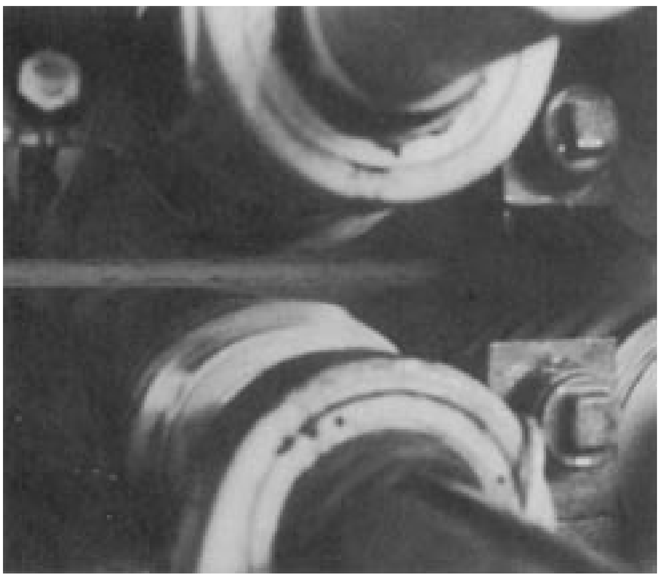


Photo 5: Roller Quenching of Q&T Steels at Bisalloy Steels

Higher tempering temperatures result in greater reductions in strength and hardness from that representative of the as-quenched condition, and corresponding enhanced levels of ductility. Choice and control of the tempering treatment is therefore vital to obtaining the required mechanical properties.

High strength structural Q&T steels typically involve tempering temperatures of 550 – 700°C, while abrasion resistant grades in which emphasis is placed on high surface and bulk hardness are tempered typically in the range 150 – 550°C.

4.2 Chemical Composition

The chemical compositions of Q&T steels are designed to ensure transformation to martensite and/or lower bainite on quenching. Sufficient hardenability must be provided to achieve the necessary depth of hardening during the quenching operation. For structural and pressure vessel applications consistent properties throughout the plate thickness must be achieved. The depth of hardening may be less critical for abrasion resistant grades if surface rather than bulk hardness is the major requirement.

Principal alloying elements in Q&T steels are manganese, nickel, chromium, molybdenum and copper, with additional hardenability often being provided by small but controlled additions of boron (typically 0.001%B). Most Q&T steels also incorporate one or more micro-alloying elements such as aluminium, titanium, niobium, vanadium or zirconium.

Boron treated steels normally contain aluminium and titanium for reasons associated with control of the boron addition during the steel making process.

Carbon contents of structural grades are typically in the range 0.12-0.20%C, while for the abrasion resistant grades increased levels up to 0.30% may be necessary.

Typical ranges of principal alloying elements are shown in Figure 1. Note however that these elements are often used in combination, such that Q&T steels can be classified as multiple low alloy heat treatable steels. Some typical alloy groupings include:

	Mn%	Ni%	Cr%	Mo%	V%	Cu%	B%
(a)	1.1	*		0.2			**
(b)	1.4	*	0.2	0.2			**
(c)	0.55	*	1.0	0.18			**
(d)	1.1	*	0.85				**
(e)	1.1	*	0.85	0.20			**
(f)	0.85	*	0.80	0.45	0.10	0.20	**
(g)	1.4	*	0.50				**
(h)	0.80	0.85	0.50	0.50	0.10	0.20	**

Note: * Nickel additions are occasionally made (0.25 – 0.50%) to enhance impact toughness and hardenability.

** Boron ranges typically from 0.0005 – 0.0015%

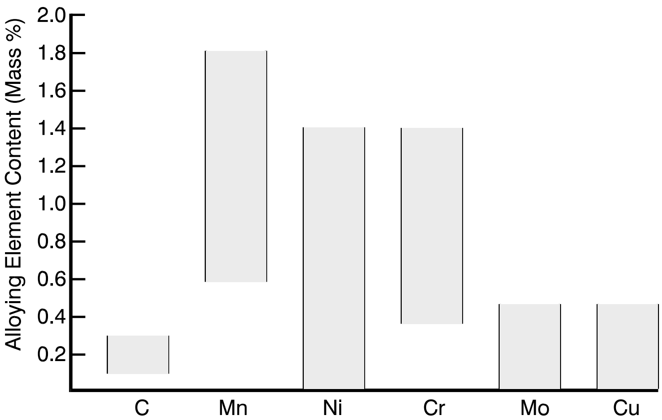


Figure 1 – Typical Ranges of Principal Alloying Elements in Q&T Steels

Composition ranges for specific elements are adjusted by the steel manufacturer according to strength and other property requirements, and to provide the necessary hardenability. Comparatively higher alloy contents are required in thicker plates, to offset the retardation in cooling rate during quenching which accompanies increase in section thickness.

Q&T steels are covered by national and international standards to a limited extent (refer to Chapter 3). However it is more common for them to be marketed under trade names such as "Bisplate", "Wel-ten" and "T-1". Designation by trade name rather than by standard specification reflects their proprietary nature and serves to highlight them as premium quality steels.

NOTE: *Trade name grades and proprietary compositions may be subject to more rapid and less publicised change than national standards. Care should be exercised when attempting quantitative analyses based on manufacturer's published chemical composition maxima, since the nominated element may not necessarily be present at all (e.g. "1.5% Ni max" does not exclude the possibility of nil intentional nickel addition). For this reason this Technical Note is substantially less quantitative and contains more general information for guidance than does WTIA Technical Note 1 The Weldability of Steels (Refer to page 25 for a full list of WTIA Technical Notes).*

4.3 Plate Surface Treatment

Australian manufactured Q&T steel plate is now available surface treated with a thin film of a water based lacquer to prevent flash rusting during storage and transport. This lacquer is applied to a shot blasted surface to a thickness of 3 to 5 µm and is designed to resist rusting, pitting and general observable degradation for up to 3 months in constant outside storage. Investigations into the welding of Q&T plate coated with a 3-5 µm thick coating has shown that:5,6

a) Ventilation appropriate to the process being used to weld the coated plate is sufficient to meet National Health and Safety Standards (NOHSC:1003) i.e: extra fume control or ventilation because of the coating is not required;

b) Weld metal diffusible hydrogen levels meet the requirements for the H10 category (less than 10 ml/100 g weld metal);

c) The measured incidence of HAZ cold cracking in CTS testing does not exceed the level encountered when welding similar uncoated plate;

d) Weld metal porosity levels are comparable with those found in welds on uncoated plate.

In normal situations, this means that the coating does not need to be removed prior to welding. If necessary, it may be removed prior to welding by wire brushing, grinding, or preheating the required area for coating removal to 100°C.

Note that the preservative lacquer is compatible with a variety of paint systems commonly used on Q&T steels. Further guidance should be sought directly from the plate manufacturer.

Guide To Cutting And Forming Operations

The information within this chapter is provided as a guide only. At the time of revising this Technical Note, many manufacturers were modifying their steel chemistries to improve their forming and cutting capabilities as well as weldability. Consequently, it is always recommended that when cutting or forming Q&T steels the manufacturer's latest literature be consulted to verify the planned cutting or forming conditions. For safety considerations, please also refer to WTIA Technical Notes 5 and 7, and section 6.1 of this Technical Note.

5.1 Cutting Operations

5.1.1 Flame Cutting

High strength structural and abrasion types of Q&T plate can be flame cut using the same equipment employed in conventional steel plate cutting. Oxygen – acetylene, oxygen – natural gas and oxygen – LPG combinations are suitable. Correct selection of nozzle size for the plate thickness being cut is important to minimise the width of the heat affected zone. WTIA Technical Note 5 provides guidance on this aspect together with optimum settings for gas pressures and cutting speeds.

When stripping plates, the use of parallel torches will help to minimise distortion.

It should be noted that preheating to 100° - 200°C may be required for many of these steel grades irrespective of the ambient temperature, due to their hardness and chemical composition. Below 10°C extra care must be taken to prevent edge cracks. It is recommended that the manufacturer's literature be consulted to verify the cutting requirements for their steel types. It is also desirable to grind out notches caused by faulty flame cutting as soon as possible, otherwise the residual stress from cutting could cause plate cracking. Particularly with the harder abrasion resistant grades, it is good practice to complete plate cutting without interruption. Do not leave a cutting job part completed overnight.

Under normal conditions the total heat affected zone (HAZ) from flame cutting will extend into the plate only 2-3 mm, as shown schematically in Figure 2.

If the flame cut surface is to be the face of a welded joint, the HAZ from flame cutting need not be removed. All slag or loose scale should be removed by light grinding, and prior to welding the cut surface should be dry and free from organic materials such as oil, grease and paint.

If the flame cut surface is to be machined, preheating to 100° -200°C prior to flame cutting is desirable, otherwise the high surface hardness of the cut edge (400-500 HB) may hinder machining.

The flame hardened edge of cut plates should be removed completely by grinding if cold forming of the cut plate is contemplated.

Q&T steels should not be stack cut because excessive heat absorption may result in over-tempering and loss of strength and hardness. Within the required preheat constraints, minimise the heat input from cutting as much as possible particularly when profile cutting.

5.1.2 Plasma Cutting

Plasma cutting of Q&T steels is highly recommended on thicknesses up to 20 mm. The process offers improvements in cutting methods particularly with respect to the lower end of the thickness range. The plasma cutting speed of

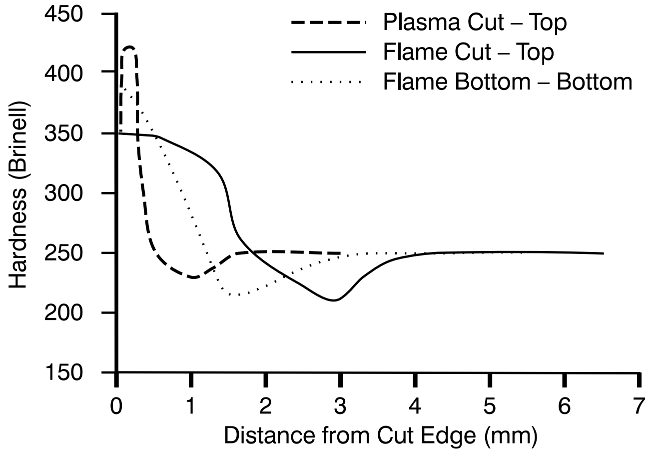


Figure 2 — Effect of Flame and Plasma Cutting on Plate Hardness for a 6 mm AS 3579 Grade 700 Steel.
Note that hardness tests were conducted using the Vickers method and converted to Brinell hardness values (HB).

return to contents next page

a 6 mm plate for example, may be up to 9 times greater than that recommended using the conventional oxygen-fuel gas cutting system. Cut quality is considered inferior, however, due to a rounding of the top edge and difficulty obtaining a square cut face on both edges.

The equipment manufacturer's literature will provide guidance on the optimum settings for nozzle size, gas composition, gas pressure and cutting speeds. Q&T steels with low alloy contents should be treated similarly to conventional structural steels.

The HAZ of a Q&T plasma cut is characterised by a higher maximum hardness level but narrower width compared to a cut using an oxy-fuel system as shown in Figure 2. The plasma cut HAZ typically extends 0.5 to 1.0mm into the plate under normal conditions. As is the case for flame cutting, complete removal by grinding is recommended if cold forming of the cut plate is contemplated. All other comments for flame cutting in Section 5.1.1 regarding preheating, removal of the HAZ, stripping and stack cutting of plates would apply to a plasma cut.

5.1.3 Shearing

High strength structural Q&T steels may be sheared with conventional machines in thicknesses up to about 25mm, although more force is needed to cut a given thickness of Q&T steel than for the same thickness of mild steel. Rated machine capacities must therefore be reduced according to the strength level of the steel to be cut, and the data presented in Figure 3 may be taken as an indicative guide.

Through hardened abrasion resistant grades should not normally be considered for shearing.

5.1.4 Other Cutting Processes

Laser cutting is a method currently employed on Q&T steels up to 10 mm thickness, beyond which productivity levels drop when compared with other processes. The laser concentrates its energy into a focussed beam resulting in low levels of excess heat. This results in a small kerf and

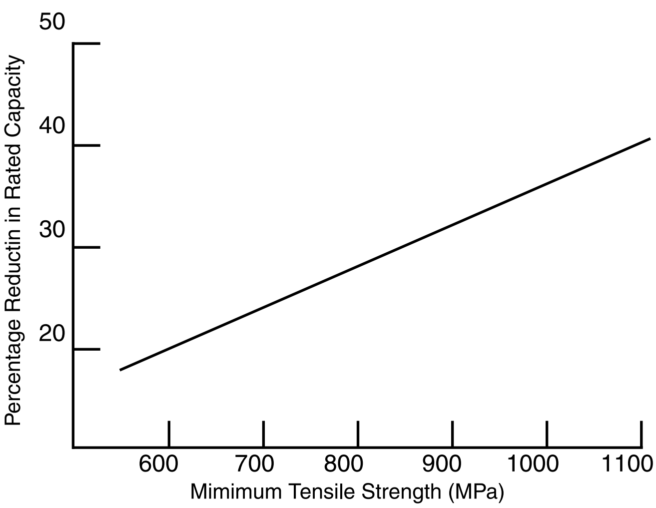


Figure 3 — Effect of Steel Strength Level on Shearing Machine Capacity.

Photo 6 — Chain Saw Guide Bars Laser Cut from *Bisplate 500*

HAZ making it particularly suitable in situations where accuracy needs to be high and distortion minimal. Table 2 shows a comparison of HAZ and kerf widths for a 6 mm Q&T steel plate, Bisplate 360 with various cutting processes.

Table 2 — Comparison of Flame, Plasma and Laser Cutting

Process	Kerf width (mm)	HAZ width (mm)
Flame cutting	0.9	1.50
Plasma cutting	3.2	0.50
Laser cutting	0.3	0.20

Other methods such as water jet cutting can be performed on Q&T steels but widespread use is limited, mainly due to their low cutting speeds.

5.2 Forming Operations

5.2.1 Cold Forming

Whilst greater power and springback allowances will be required than for conventional structural steels, all common grades of Q&T steels may be cold formed by roll or press bending. The power required is approximately proportional to the yield stress of the steel being formed.

The extent of springback during cold forming can be predicted from formulae such as the Gardiner expression:[3]

$$\frac{R_o}{R_f} = \frac{4(R_o\sigma_y)^3}{Et} - \frac{3(R_o\sigma_y)}{Et} + 1$$

where R_o = radius of the former

R_f = radius of the bend after springback

σ_y = yield stress of the steel

E = modulus of elasticity of the steel

t = plate thickness

One example of the use of this expression to predict springback is shown in Figure 4.[4]

return to contents next page

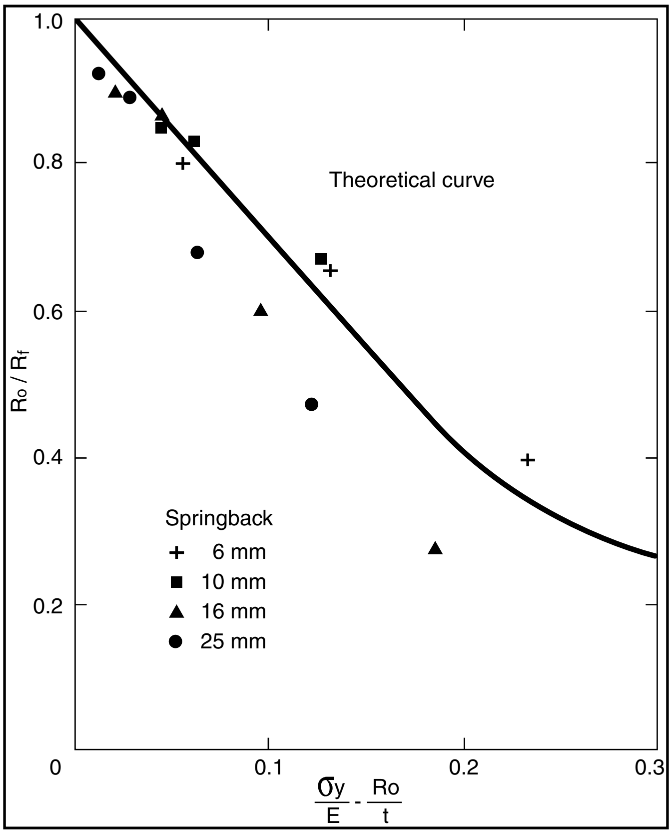


Figure 4 — Prediction of Springback During Cold Forming AS 3597 Grade 700 Plates.[4]

The minimum bend radius increases with the hardness and strength of the grade being formed – refer to Table 3. In the cases of the abrasion resistant grades it is recommended that where possible the bend axis be transverse to the plate rolling direction, since much larger bend radii are required to bend about a longitudinal axis. It is desirable to use 500 HB plate without bending, however if unavoidable it is recommended that plate exceeding 12 mm in thickness should not be bent about the longitudinal axis.

Photo 7: Flexible Side Tipper from 6mm Bisplate 360

In very cold conditions it is advisable to heat the plate slightly (30°C) prior to forming.

During press bending it is recommended that the supporting vee former should be well lubricated or roller guides employed.

Flame cut edges should be dressed by grinding or machining prior to forming ensuring that hardened edges are removed completely.

5.2.2 Hot Forming

Hot forming is generally not recommended because if tempering temperatures are exceeded, the properties of the steel will be impaired. If hot forming is unavoidable it is essential that the maximum re-heat temperatures be closely controlled and kept below the tempering temperature of the particular grade. Under these circumstances, or if there is any doubt as to the appropriateness of forming operations, it is recommended that the manufacturer be consulted.

Table 3 – Minimum Bend Radii for Cold Forming

Grade	Bending Direction*	Plate Thickness (mm)			
		>3.2 <6	≥6 ≤12	>12 <32	≥32 ≤50
High Strength Structural					
AS 3597 grade 500	T	1.5 t	1.0 t	2.0 t	2.0 t
	L	1.5 t	1.5 t	2.5 t	2.5 t
AS 3597 grade 600	T	1.5 t	1.5 t	2.5 t	2.5 t
	L	1.5 t	2.0 t	3.0 t	3.0 t
AS 3597 grade 700	T	1.5 t	2.0 t	2.5 t	2.5 t
	L	1.5 t	2.5 t	3.0 t	3.5 t
Abrasion Resistant					
320 HB	T	2.5 t	3.0 t	3.5 t	5.0 t
	L	3.0 t	4.0 t	4.5 t	7.0 t
360 HB	T	3.0 t	3.5 t	4.0 t	6.0 t
	L	4.0 t	4.5 t	5.5 t	N.R.
400 HB	T		4.5 t	6.5 t	N.R.
	L		8.0 t	N.R.	N.R.
500 HB	T		5.0 t	8.0 t	N.R.
	L		9.0 t	N.R.	N.R.

* T = bend axis transverse to the plate rolling direction
L = bend axis longitudinal to the plate rolling direction
N.R. = not recommended

Note: Refer to the manufacturer’s literature when approaching the critical limits of formability.

Welding

6.1 Safety

When welding Q&T steels appropriate safety precautions are required to protect personnel and equipment from damage. The reader should therefore refer to WTIA Technical Note 7 and appropriate Australian Standards such as the AS 1674 series *Safety in welding and allied processes* (in 2 parts) and AS 2865 *Safe working in confined spaces.*

Because these steels are "low alloy steels" and are typically welded with alloyed welding consumables which contain small amounts of elements such as manganese, nickel, chromium, molybdenum etc., readers should be aware of their obligation under the National Model Hazardous Substances Regulations declared by Worksafe Australia (being adopted in all states of Australia) to verify that the welding of these materials does not cause hazardous levels of fume to be generated.

Where the steels have been prepainted or coated, additional safety precautions may be required when welding through the coating. Note that in cases where the applied coating is a specific "weld-through-primer" whose thickness is restricted to facilitate welding, additional fume control may not be required. The water based lacquer mentioned in Section 4.3 is an example where coating thickness has been controlled so that additional ventilation is not required over and above that required for the process being used. Please refer to WTIA Technical Note 7, appropriate Material Safety Data Sheets (MSDSs) and the manufacturer's literature for guidance.

6.2 Metallurgical Effects of Welding

The relatively high hardenability, necessary to develop the required mechanical properties by hardening and tempering, renders Q&T steels more susceptible to the thermal effects of welding than conventional carbon and carbon-manganese structural steels. Depending on weld thermal cycle, metallurgical changes due to welding may range from overtempering, resulting in loss of strength, hardness and possibly toughness, to the formation of undesirable microstructures causing hardening and embrittlement.

Use of correct welding procedures is therefore of fundamental importance. When proper procedures are employed Q&T steels can be welded satisfactorily by all major welding processes.

Q&T steels differ from conventional steels, so welding procedures and practices, while comparatively simple and straightforward, are also different. In particular it is necessary to observe limitations of **both** maximum and minimum total weld heat inputs, as illustrated schematically in Figure 5.

Note that the concept of total weld heat input involves consideration of:

a) Preheat temperature

b) Interpass temperature

c) Arc energy input (Q in kJ/mm)

$$\text{where } Q = \frac{E \times I \times 60}{S \times 1000}$$

E = arc voltage in volts (RMS value for a.c.)

I = welding current in amperes (RMS value for a.c.)

S = welding speed in mm/min

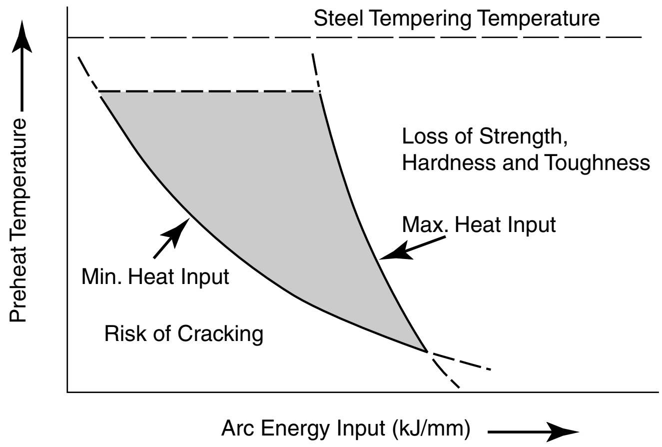


Figure 5 – Total Weld Heat Input Relationships for Welding Q&T Steels

return to contents next page

The shaded area defined by the curves in Figure 5 denotes a permissible heat input "window" limited on the low side by risk of excessive hardening and cracking, and on the high side by loss of strength and hardness due to overtempering and possible loss of toughness due to re-transformation on cooling to upper bainitic microstructures.

The wedge shape of the window favours the use of low to moderate arc energies together with substantial levels of preheat in order to secure adequate tolerance to total heat input variations likely under practical shop or field welding conditions.

The numerous combinations of specific alloy groupings and steel tempering temperatures employed in commercially available high strength structural and abrasion resistant Q&T steels currently preclude a more quantitative treatment of Figure 5 while at the same time maintaining general applicability.

Similarly, perusal of manufacturer's technical literature reveals substantial differences in preheat and arc energy input recommendations. For this reason, although the information presented in this chapter provides general guidance in the welded fabrication of Q&T steels, it is recommended that in selecting welding procedures for critical or complex joints:

a) reference is made to manufacturer's literature or test data specific to the trade name and grade of steel to be welded; or
b) welding procedures be verified by qualification tests (e.g. as in AS/NZS 1554.4 and AS 1210); or
c) welding procedures be established by simulated full scale tests.

Notwithstanding the above noted comments, carbon equivalent related formulae, often referred to as cracking parameters, have been derived for specific Q&T steels and can be used to predict minimum preheat temperatures necessary to avoid risk of cracking.[7,8]

In addition to chemical composition, cracking parameters may take into account intensity of restraint, weld metal diffusible hydrogen content and plate thickness to be welded. Much of the data from which cracking parameters have been developed relate to the Y groove or Tekken weldability test, and as such are particularly applicable to the first pass of butt welds or tack welds made under conditions of high restraint. Arc energy input for Y groove cracking tests normally is set at 1.6-1.7 kJ/mm. Preheat temperatures derived from P_{cm}, P_w or similar cracking parameters then may only be applicable to arc energy inputs of this order.

One widely quoted such analysis yields the following results:[7]

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

$$P_w(\%) = P_{cm} + \frac{H_D}{60} + \frac{R_F}{40000}$$

where H_D = weld metal diffusible Hydrogen (ml/100g)

R_F = restraint intensity factor usually less than 40 x plate thickness

Minimum preheat (°C) = 1440 P_w – 392

More recent research has sought to incorporate arc energy input into cracking parameters and to extend their usefulness to a wider range of chemical compositions, alloy groupings and plate thicknesses.9,10

6.3 Welding Processes

Both high strength structural and abrasion resistant grades of Q&T steel are readily weldable by the conventional arc welding processes such as manual metal arc welding (MMAW), flux cored arc welding (FCAW), gas metal arc welding (GMAW) and by submerged arc welding (SAW).

6.4 Welding Consumables

Consumables providing matching strength to the structural grades are available for all processes, and these are commonly used for butt welds. For fillet welding it may be preferable to use suitable consumables of under-matching strength (refer Section 6.5.4). With abrasion resistant grades welding is usually for attachment purposes only and consumables providing under-matching strength are usually used. Welding consumables which are suitable for welding the various grades of Q&T steels are readily available from all leading consumable manufacturers. Tables 4a and 4b are general welding consumable selection guides for Q&T steels based on the Australian Standard and the American Welding Society (AWS) classifications respectively. Specific examples of these consumable classifications are given in Appendix A. The lists are not exhaustive and other consumable types may be suitable. Contact your consumable manufacturer for a complete listing.

Q&T steels are more susceptible than conventional structural steel to hydrogen cold cracking and so utmost care must be taken with the weld consumables to ensure that absorption of moisture is minimised. For guidance refer to WTIA Technical Note 3 *Care and Conditioning of Arc Welding Consumables.*

In MMAW, only electrodes with basic hydrogen controlled coatings should be chosen, and before use they should be baked according to the manufacturer's recommendations. After baking they should be stored in hot boxes at 100° – 150°C to avoid moisture pick-up from the atmosphere. Should the electrode manufacturer make specific recommendations covering conditioning and pre-treatment of electrodes prior to use, such recommendations must be followed.

Table 4a – Welding Consumable Selection Guide for Q&T Steels (AS Classifications)

0.2% Proof Stress (AS 3597)		500 MPa	600 MPa	700 MPa	Abrasian Resistant Grades (320-500 HB)
MMAW Consumables[1] **Warning:** Only use hydrogen controlled consumables					
STRENGTH LEVEL	Matching	E55XX / E62XX†	E69XX*	E76XX	N.R.
	Lower	E48XX	E55XX	E55XX / E62XX	E55XX
HARDNESS	Lower	E48XX	E48XX	E48XX	E48XX
	Matching	N.R.	N.R.	N.R.	1430-AX, 1855-AX**
GMAW Consumables[2]					
STRENGTH LEVEL	Matching	W55XX / W62XX†	W69XX*	W76XX	N.R.
	Lower	W50XX	W55XX	W62XX / W69XX	W55XX
HARDNESS	Lower	W50XX	W50XX	W55XX	W50XX
	Matching	N.R.	N.R.	N.R.	1855-BX**
FCAW Consumables[3]					
STRENGTH LEVEL	Matching	W55XX.X / W62XX.X†	W69XX.X*	W76XX.X	N.R.
	Lower	W50XX.X	W62XX.X	W62XX.X	W55XX.X
HARDNESS	Lower	W50XX.X	W55XX.X	W55XX.X	W50XX.X
	Matching	N.R.	N.R.	N.R.	1430-BX, 1855-BX, 1860-BX**
SAW Consumables[4]					
STRENGTH LEVEL	Matching	W55XX / W62XX†	W69XX.X*	W76XX.X	N.R.
	Lower	W50XX	W50XX	W50XX	W50XX
HARDNESS	Lower	W40XX	W40XX	W40XX	W40XX
	Matching	N.R.	N.R.	N.R.	1855-BX**

Notes
1. MMAW – AS/NZS 1553.1-1995 and AS 1553.2-1987 consumable classification
2. GMAW – AS 2717.1-1984 consumable classification
3. FCAW – AS 2203-1990 consumable classification
4. SAW – AS 1858.1-1996 and AS 1858.2-1989 consumable classification

X = A variable – any
† E62XX and W62XX type consumables overmatch the strength requirements but may be used.
* These consumables may be difficult to obtain. In some cases E62XX or W62XX type consumables may be subsituted, otherwise use E76XX or W76XX types.
** AS 2576 and WTIA TN 4 classifications
N.R. Not recommended

Table 4b – Welding Consumable Selection Guide for Q&T Steels (AWS Classifications)

0.2% Proof Stress (AS 3597)		500 MPa	600 MPa	700 MPa	Abrasian Resistant Grades (320-500 HB)
MMAW Consumables[1] **Warning:** Only use hydrogen controlled consumables					
STRENGTH LEVEL	Matching	E80XX / E90XX†	E100XX*	E110XX	N.R.
	Lower	E70XX	E80XX	E80XX / E90XX	E80XX-X
HARDNESS	Lower	E70XX	E70XX	E70XX	E70XX
	Matching	N.R.	N.R.	N.R.	1430-AX, 1855-AX**
GMAW Consumables[2]					
STRENGTH LEVEL	Matching	ER80S-X / ER90S-X†	ER100S-X*	ER110S-X	N.R.
	Lower	ER70S-X	ER80S-X	ER90S-X / ER100S-X	ER80S-X
HARDNESS	Lower	ER70S-X	ER70S-X	ER80S-X	ER70S-X
	Matching	N.R.	N.R.	N.R.	1855-BX**
FCAW Consumables[3]					
STRENGTH LEVEL	Matching	E8XTX-X / E9XTX-X†	E10XTX-X*	E11XTX-X	N.R.
	Lower	E7XT-X	E9XTX-X	E9XTX-X	E8XTX-Y
HARDNESS	Lower	E7XT-X	E8XTX-X	E8XTX-X	E7XT-X
	Matching	N.R.	N.R.	N.R.	1430-BX, 1855-BX, 1860-BX**
SAW Consumables[4]					
STRENGTH LEVEL	Matching	F8XX / F9XX†	F10XX*	F11XX	N.R.
	Lower	F7XX	F7XX	F7XX	F7XX
HARDNESS	Lower	F6XX	F6XX	F6XX	F6XX
	Matching	N.R.	N.R.	N.R.	1855-BX**

Notes
1. MMAW – AWS A5.1-91AND AWS A5.5-81 consumable classification
2. GMAW – AWS A5.18-93 AND AWS A5.28-79 consumable classification
3. FCAW – AWS A5.20-79 AND AWS A5.29-80 consumable classification
4. SAW – AWS A5.17-89 AND AWS A5.23-90 consumable classification

X = A variable – any
† E90XX, ER90S, E9XTX and F9XX type consumables overmatch the strength requirements but may be used.
* These consumables may be difficult to obtain. In some cases E90XX, ER90XX, E9XTX, or F9XX type consumables may be substituted, otherwise use E110XX, ER110S, E11XTX or F11XX types.
** AS 2576-1982/WTIA TN 4 classifications
N.R. Not recommended

return to contents next page

In GMAW, the shielding gas protects the weld area from exposure to air and so the resultant weld metal hydrogen content is low. Filler wires must be dry, smooth and free from corrosion or other foreign matter, and the weld groove should be kept clean and free from moisture, oil, rust and anti-spatter materials.

The gas shielded FCAW process is particularly suitable for welding Q&T steels owing to the low hydrogen content associated with this process. The flux cored wires are normally used with CO_2 gas shielding or argon-CO_2 mixtures.

Any gas or gas mixture used in GMAW or FCAW should be of welding grade having a dew point of –35°C or lower.

In SAW, the hydrogen content of weld metal is particularly influenced by the type of flux employed. The flux must be fully dried before use, in accordance with the welding material supplier's recommended practice. After drying, fluxes must be kept free from moisture in the same manner as for electrodes for manual welding. Where flux is re-used, flux recycling systems should include sieves and magnetic particle separators such that the flux remains in a satisfactory condition for re-use. Flux fused during the welding operation should not be re-used.

6.5 Welding Procedures

The recommendations in this Technical Note are provided as a guide to the user in the absence of manufacturer's data and are based on material property evaluations and service experience. As such, they can be used with a high degree of confidence, however, they are a guide only and it cannot be guaranteed that cracking will never occur. These preheat, interpass temperature and weldability recommendations do not over-ride the user's obligation to demonstrate suitability of the welding procedures through the use of procedure qualification tests as prescribed by applicable fabrication standards. Additionally, it is assumed that welding is performed by welders capable of complying with the minimum requirements of AS/NZS 1554.4 section 4.11.2 *Welder Qualifications.*

It should also be noted that when applying the preheat conditions given in Table 5, they are recommended minimum temperatures only and assume a moderate degree of joint restraint. In cases of high joint restraint, particularly when high strength welding consumables are specified, it may be necessary to increase the preheat above the minimum level given to avoid cracking, particularly in the weld metal. In any event, the recommended interpass temperature must not be exceeded.

6.5.1 Joint Combined Thickness

Just as in the case of welding structural and low alloy steels, the total effective thickness of the joint is an important consideration when developing welding procedures. This effective thickness is usually referred to as the "Combined Thickness" and is important because the joint configuration will affect the weld cooling rate and thus properties of the welded joint. Similar details on its importance are given in WTIA Technical Note 1.

The concept of combined thickness is required to address the cooling rate, caused by the abutting or mating sections forming a weld. The combined thickness is shown for a range joints in Figure 6 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 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 7 below. The formula to calculate the effective thickness is:

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

where W is the width of the part (less than 75 mm);
t is the actual thickness of the part;
T_E is the effective thickness for calculation purposes

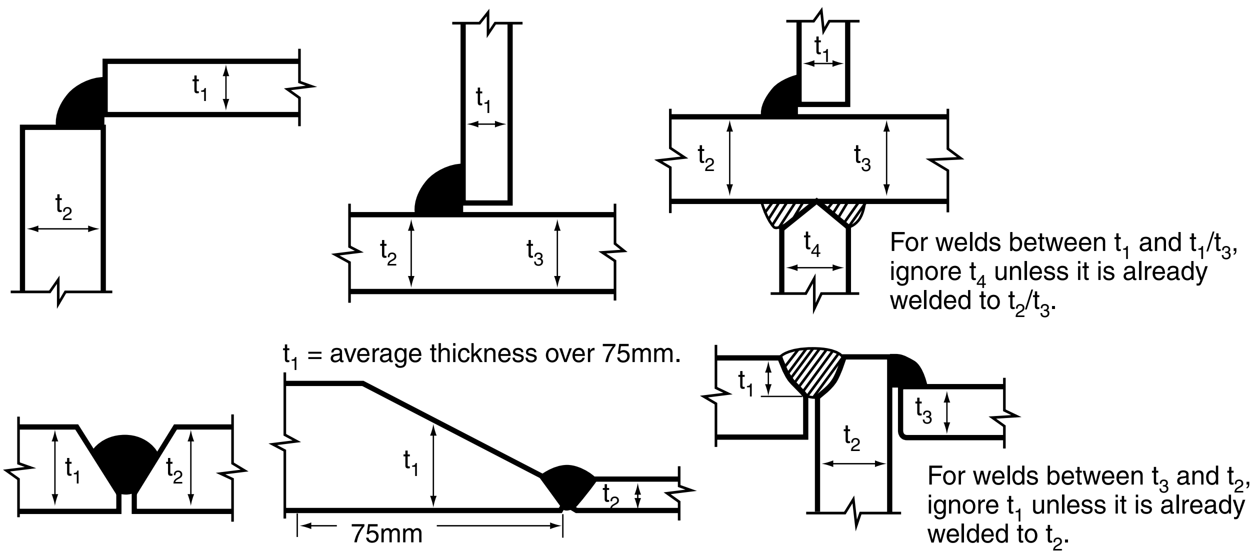
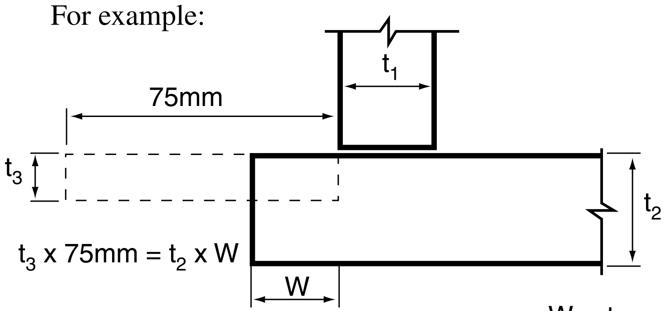


Figure 6 – Calculation of Combined Thickness

return to contents next page

For example:



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

Figure 7 – Effective Combined Thickness

When bars or rod sections are welded, often their widths or diameters are less than 75 mm, and an appropriate method of 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 = $0.01d^2$ which is derived by:

$$T_E = \frac{\pi x d^2}{4x75} \approx 0.01d^2$$

For welded joints using backing bars, an adjustment in combined thickness is not normally considered necessary as the relative size of the backing strip is very small and thus has minimal affect on cooling rates. If the size of the bar is considered significant, the technique shown in Figure 7 can be used to give an effective thickness which is then included when calculating the combined thickness.

6.5.2 Tack Welding

Tack welds require special care because of the abnormal stresses and high cooling rates experienced by the adjacent material. Cracking may be avoided by employing the same preheat and total heat input procedures as used in ordinary welding (refer to manufacturer's recommendations or Table 5) and using welding consumables with the lowest possible strength ratings and by depositing the subsequent weld runs as soon as possible after tacking.

6.5.3 Butt Welding

For complete penetration butt welds the joint designs shown in AS 1554.4 are recommended for general use. For plate thicknesses over 12 mm use of the symmetrical double-vee groove is recommended since back-gouging makes the two sides of the weld deposit almost equal in thickness and thereby minimises angular distortion.

For critical or complex joints, notice should be taken of the comments in Chapter 3 of this Technical Note regarding particular steel manufacturer's recommendations in relation to pre-heat and total weld heat input. However the limits imposed in Table 5 on preheat, interpass temperature and maximum arc energy input can be taken as a general guide. Note that the preheated area should include material approximately 75 mm each

Table 5 – Recommended Minimum Preheat Temperatures, Maximum Interpass Temperatures and Maximum Arc Energy Inputs.

Grade	Joint Combined Thickness (mm)			
	<26	≥26 <50	≥50 <100	≥100
MINIMUM PREHEAT TEMPERATURES °C				
High strength structural grades				
AS 3597 – 500 grade	10	50	75	**
AS 3597 – 600 grade	10	50	75	**
AS 3597 – 700 grade	10	50	75	140
Abrasion resistant grades				
320 HB	50	75	125	150
360 HB	50	75	125	150
400 HB	100	150	150	**
500 HB	100	150	150	**
MAXIMUM INTERPASS TEMPERATURES °C				
All grades	150	175	200	220
MAXIMUM ARC ENERGY INPUT – kJ/mm				
MMAW	2.5 †	3.5	4.5	5.0
GMAW	2.5 †	3.5	4.5	5.0
FCAW	2.5 †	3.5	4.5	5.0
SAW	2.5 †	3.5	4.5	5.0

Notes

** Refer to the manufacturer for availability and preheat requirements

† For joint combined thicknesses of less than 26 mm in high strength structural grades, the maximum arc energy input may need to be limited to 1.5 kJ/mm max. in specific applications. Refer to the material manufacturer for further guidance.

This table is provided as a guide and only applies in the absence of specific recommendations from the material manufacturer. Note the qualification warning regarding effective plate thickness given in sections 6.5.3 and 6.5.4.

side of the prepared joint, and the temperature should be checked (at least 1 minute minimum after removal of the heating source) with temperature sensitive crayons, contact pyrometer or surface thermometer.

WARNING: *Where the manufacturer's literature provides preheat, interpass and heat input recommendations in reference to plate thickness, such literature refers to joints made of equal thickness plates in the butt configuration. To use such literature, calculate the joint combined thickness as given in section 6.5.1 of this Technical Note and then halve the result to give an "effective plate thickness" for that situation.*

When the preheat temperature is high and/or welding is concentrated locally, the interpass temperature may become too high and adversely affect the toughness of the weld metal or heat affected zone. Interpass temperatures in multi-pass welding should therefore be maintained at or above the preheat temperature, but below the maximum values listed in Table 5. Measurements of the interpass temperature should be taken as close to the welding line as possible.

Due to heat input restrictions, care must be exercised in manipulating electrodes and welding torches. The stringer bead technique should be employed as much as possible in flat, horizontal and overhead welding. In MMAW vertical welding where weaving is required, use electrodes of small diameter (3.2-4.0 mm) and restrict the width of weaving to no more than 2.5 times the electrode diameter. Do not use a full weave technique. A number of weld runs having an arc energy within the range 1.25-2.5 kJ/mm is preferable to heavy single welds deposited at higher arc energy inputs.

6.5.4 Fillet Welding in Fatigue Applications

Good fillet welding techniques are even more important in welding Q&T steels when the structure is to be subject to fatigue loadings. Welded joints in the high strength structural Q&T steels are often loaded to higher stresses than in the case of lower strength steels, it is essential that welds be smooth, correctly contoured, and well flared into the legs of the joined pieces. The runs of each fillet weld must have good penetration, particularly at the root, but must not undercut the joined pieces, see Figure 8.

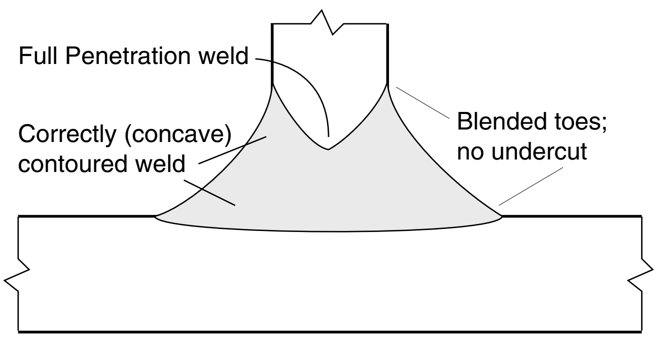


Figure 8 – Fillet Welding in Fatigue Applications.

6.5.5. Fillet Welding Thick Plates

When thick plates (> 32 mm) are joined there is a danger of toe cracking at or near fillet welds. This danger can be overcome by applying preheat appropiate to the combined joint thickness. Two additional mitigative actions are listed below:

a) Use of lower strength welding consumables for fillet welds than would be used for butt welds. Many fillet welds or corner joints do not required the same strength as that require in butt joints. Lower strength consumables are generally more ductile than higher strength consumables and are suitable for use in fillet welds in these steels. In multi-run fillet welds, only the first pass need be of lower strength (see Figure 9). Note that design requirements ultimately dictate the allowable strength of the weld deposit.

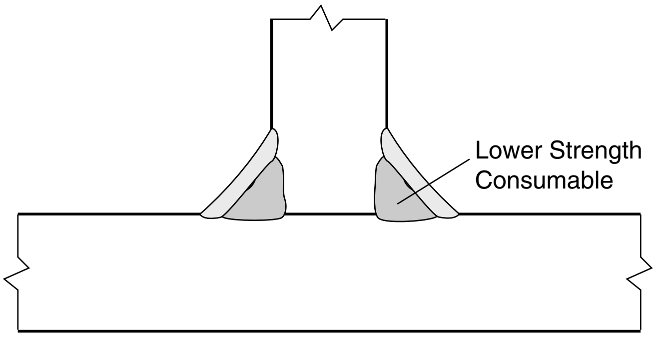


Figure 9 – Use of Low Strength Electrode in First Pass of Fillet Weld.

b) Buttering the toe area of fillet welds. Buttering the area (i.e. applying a low strength filler metal) where toe cracks are expected is also an effective means of crack prevention. A bead is laid in the toe area, then ground off prior to the actual fillet welding. This butter weld bead must be located so that the toe passes of the fillet will be laid directly over it during subsequent welding (see Figure 10).

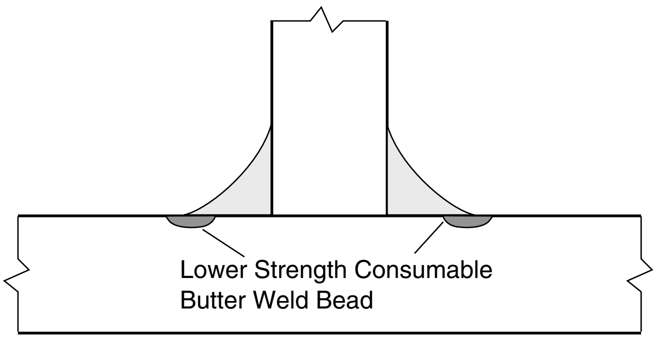


Figure 10 – Buttering of Fillet Welds to Reduce Toe Cracking.

WARNING: *Where the manufacturer's literature provides preheat, interpass and heat input recommendations in reference to plate thickness, such literature generally refers to joints made of equal thickness plates in the butt configuration. Calculate the joint combined thickness as given in section 6.5.1 of this Technical Note. In the fillet welding situation, this may mean that more preheat will be required to compensate for the higher cooling rate of the joint configuration.*

6.5.6 Hard Capping of Welds

With abrasion resistant grades of Q&T steels, preferential wearing of welds can occur. A suggested method of overcoming this problem is by overlaying or capping a previously deposited joining weld with one or more layers of hardfacing material. The hardness, abrasion and impact properties of the hardfacing material should be similar to the Q&T abrasion resistant grade base metal and in particular be suitable for the service conditions to be met.

Care should be exercised in following the procedures laid down for welding Q&T steels ie; preheat, heat input, interpass temperature etc., when depositing overlaying or capping welds.

A wide range of hardfacing consumables is available and assistance in selecting the most appropriate consumable for a given service condition can be obtained from WTIA Technical Note 4.

6.5.7 Stud Welding

Welding studs to high strength and wear resistant steels offers quick and economic attachment. All Q&T grades can be stud welded readily, provided the following recommendations are observed:

a) The stud must be of a low carbon mild steel, complying with the requirements of AS 1554.2;

b) As the amount of total weld heat input is critical in relation to the amount of cracking in the HAZ, it is important that weld time and current are accurately controlled;

c) Longer weld times should be used to create a pre-heat condition during the weld process. Weld times gener–ally 10% longer than optimum stud welding settings used for mild steel have been shown to produce the best results.

Note that optimum weld times are influenced by stud size and shape, parent material thickness, material composition and type of welding equipment being used.

6.5.8 Welding Q&T Steel to Other Steels

When welding Q&T steel to *other* steels, the weldability of both steel types must be considered. The general principle to be followed is that all the foregoing procedures regarding total heat input, electrode manipulation, care and maintenance of consumables, and control of consumable and weld metal hydrogen content should be followed (i.e. procedures should be established as if welding were being performed on Q&T steel only) whilst the strength of consumable should be based on the non Q&T steel. In the case of structural and mild steels, lower strength low hydrogen consumables such as the E4816 or E4818 class of MMAW electrode, and comparable wire-flux (SAW) or wire-gas combinations (for GMAW and FCAW processes) should be used.

Minimum preheat is set by referring to both WTIA Technical Note 1 (WTIA Technical Note 18 in the case of castings) and Table 5 of this Technical Note. The steps are:

1. Referring to Technical Note 1 (or Technical Note 18 for castings), calculate the preheat required given the hydrogen control employed, combined thickness of the joint and chemistry of the non Q&T steel;
2. Note the preheat required for the given combined thickness and grade of Q&T steel from Table 5 or the manufacturer's literature;
3. The required minimum preheat for the joint will be the higher of (1) and (2);
4. The maximum interpass temperature is obtained by referring to Table 5 or the manufacturer's literature for that grade of Q&T steel and the combined joint thickness;
5. In cases where the required minimum preheat is higher than the allowed maximum interpass temperature, two options are given below with option (a) the preferred method.
   a) Preheat the *other* steel to the level required in (1), and then weld a buttering layer of at least two runs thickness in the region to be joined to the Q&T steel. This will then place the HAZs of subsequent passes within the weld metal rather than in the *other* steel. On completion of the buttering layer, the preheat is lowered to that required by the Q&T steel and the joint completed as if welding Q&T steel, noting restrictions on the interpass temperature and heat input.

      OR;

   b) Preheat the Q&T steel to the required minimum level, then weld a buttering layer as recommended in (a) above noting restrictions in interpass temperature and heat input. On completion of the buttering layer, increase the preheat to that required by the *other* steel and then complete the joint as if welding the *other* steel only. Note that the maximum interpass temperature must not be allowed to exceed the tempering temperature of the Q&T steel. Method (b) should only be used in cases where (a) is unsuitable.

When the *other* steel is a stainless steel, refer to WTIA Technical Note 16 for the appropriate consumable type, preheat and interpass requirements, heat input restrictions and then follow the steps outlined above.

In all other cases or where doubt exists as to the suitability of these recommendations, expert guidance should be sought from the WTIA.

6.5.9 Welding High Tensile Steel Bolts

Welding high tensile steel bolts (e.g. class 8.8) is **NOT** recommended as the bolt properties are easily degraded and prone to cracking when welded. This occurs because the chemistry of the bolt material is rarely known and may be inconsistent from manufacturer to manufacturer or batch to batch. The bolt standard (AS 1252) merely identifies chemistry requirements as 0.55% C maximum. Additionally the welding of smaller diameter bolts is likely to cause excessive softening and loss of strength in the bolt.

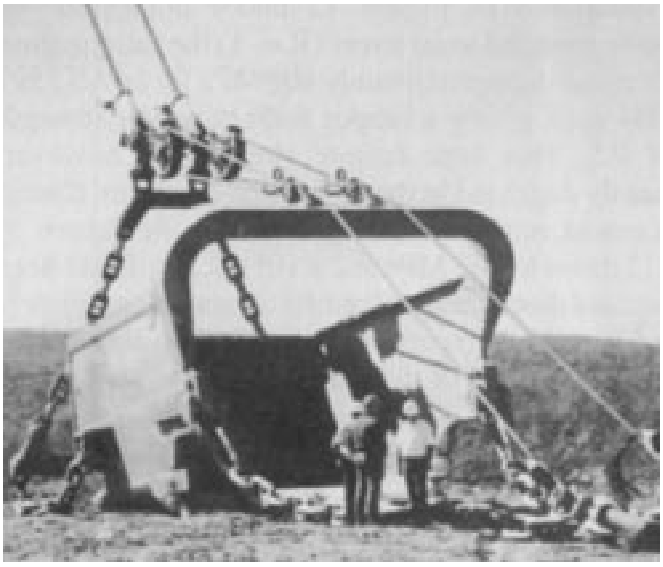


Photo 8: Typical Dragline Bucket Manufactured using Q&T Structural Grades lined with Q&T Wear Plates and Alloy Steel Castings

6.5.10 Back Gouging

Root runs may be back gouged by the air-carbon arc process using carbon rods preferably by the plasma gouging process. Preheating procedures for gouging should be the same as those used for welding. The surface hardened layer (air-carbon arc process) of approximately 2 mm in depth must be removed by disc grinding following gouging. It is advisable to perform the gouging on the same day that subsequent welding is to be carried out. Back gouging is generally not required if good fit up and appropriate welding techniques are employed.

6.5.11 Stress Relief

Stress relief is applied to reduce residual stresses resulting from welding and induce softening of the hardened section of the heat affected zone. However, if applied unthinkingly, stress relief can have serious deleterious effects on the properties of Q&T steels. Because of the risk of stress relief cracking, post weld heat treatment of these materials should not be undertaken unless it is absolutely necessary.

Stress relieving temperatures must be kept at least 30°C below the tempering temperature in accordance with Appendix D of AS 3597. For AS 3597 Grade 700 type steels (e.g. "Bisplate 80" or "Wel-ten 80C") this condition would generally permit a stress relieving temperature range of 540°–580°C. The lower tempering temperatures of the abrasion resistant grades mean that thermal stress relief can not be applied in these cases.

The toes of weld beads should be blended by grinding prior to stress relieving in order to prevent stress relief cracking.

WARNING: *Care must be taken to avoid excessive reduction of thickness adjacent to the weld.*

6.6 Welded Joint Performance

6.6.1 General

During welding the parent material is heated to a temperature which depends on the distance from the fusion boundary. This area becomes the Heat Affected Zone (HAZ). The temperature gradient is quite steep so that whilst peak temperatures of approximately 1500°C are reached adjacent to the fusion boundary, material only 3-4 mm away may only reach 400°C or less. The temperature reached at a given point along the HAZ has a significant influence on the subsequent microstructure and mechanical properties. Because of its prior heat treatment, the HAZ of a welded joint in Q&T steel exhibits different characteristics from those of a welded joint in mild steel plate. This is illustrated in a generalised way in Figure 10.

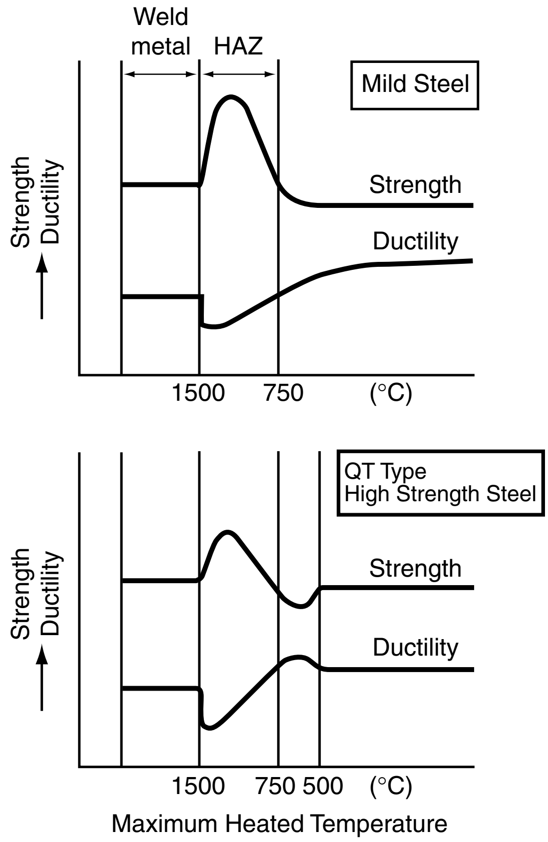


Fig. 10 – Strength and Ductility Distributions of Welds in Steels.[11]

In welded joints in Q&T steels strength and hardness reach a maximum in the HAZ towards the fusion boundary and drop to a minimum in the parent plate beyond the visible HAZ, where overtempering occurs. Conversely, ductility is at as minimum in the coarse grained HAZ and rises to a maximum in the softened parent material before dropping somewhat to a level representative of the parent plate.

Overall joint strength and toughness depends on many factors including total weld heat input (which influences the magnitude and depth of the thermal gradients) choice of consumable, particularly in relation to its strength and chemical composition, and joint configuration and dimensions.

return to contents next page

6.6.2 High Strength Structural Grades

If produced under appropriate welding conditions, welded joints in high strength structural Q&T steels offer attractive combinations of strength and toughness, and variations in properties across the joint can be minimised. Qualification test requirements of the relevant codes can be readily satisfied.

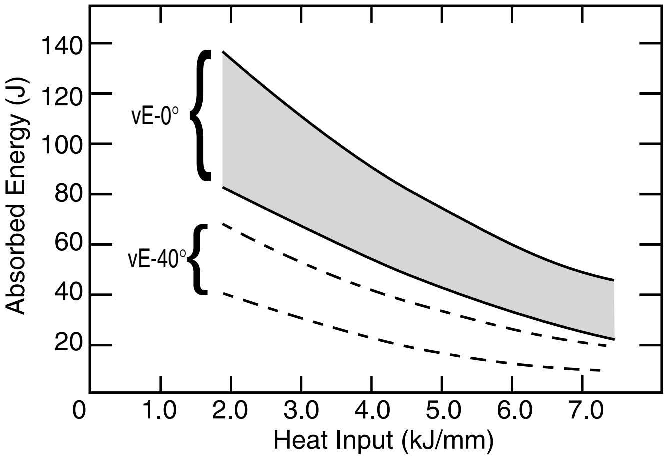


Figure 11 – Typical Effect of Heat Input on HAZ toughness for an AS 3597 Grade 700 Steel (Ref. 16).

Typical tensile and bend tests results for welded joints in high strength structural Q&T steels produced by each of the common arc welding processes show that softening of the HAZ does not affect the joint tensile strength in actual welded structures due to overall plastic restraint on the total joint.

The effect of total weld heat input on the Charpy notch toughness of welded joints at two test temperatures (0°C and -40°C) illustrated in Figure 11 emphasises the need to restrict the total heat input according to the desired level of toughness.

Advanced design codes allow use to be made of the high fatigue limits of Q&T steels. For example, the higher design stress supplement to the SAA Unfired Pressure Vessels Code, Supplement No. 1 to AS 1210, provides for a permitted design alternating fatigue stress of 140 MPa in these steels compared with 90 MPa for conventional pressure vessel steels.

As illustrated in Figure 12 under conditions of completely reversed axial stress (R = -1) the fatigue limit at 2 x 10^6 cycles is approximately 400 MPa for an AS 3597 grade 700 steel, giving a fatigue limit to tensile strength ratio of 0.5. This high fatigue strength is, however, significantly degraded in the as-welded condition if weld reinforcement remains, and in the example shown in Figure 12 drops to 160 MPa at 2 x 10^6 cycles. It has been demonstrated that if the weld reinforcement is completely removed from full strength butt welds then the fatigue limit approaches that of the parent plate.

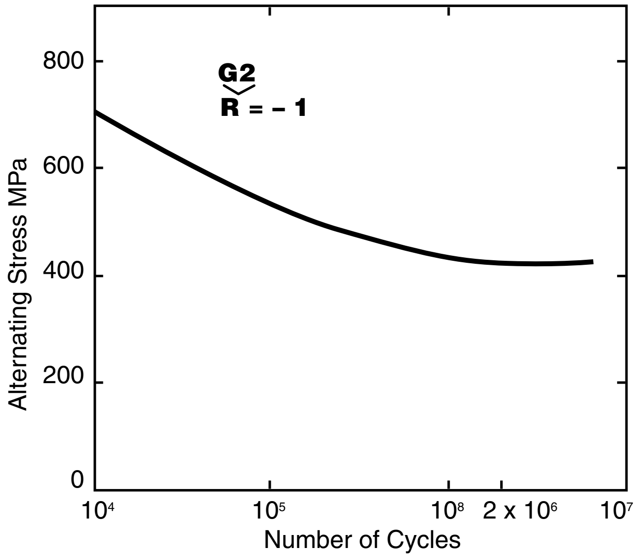
In applications where fatigue strength is the important design parameter, consideration must be given to design details and fabrication quality. The elimination of small (surface breaking) weld discontinuities or stress concentrations by grinding of weld toes or GTAW dressing and the reduction of residual stress patterns around the weld by thermal stress relieving or shot peening are important in extending the fatigue life. AS 1554.4 offers rules on the permissible levels of imperfections, testing requirements and workmanship tolerances for ‘FP’ category welds. British Standard PD6493 relating to critical defect assessments, WTIA Technical Note 10 *Fracture Mechanics* and the manufacturer’s literature will provide additional guidance when designing against fatigue.

Photo 9: Underground Longwall Mining Operation – using roof supports constructed from Q&T structural grades and pan lines using Q&T wear plates.

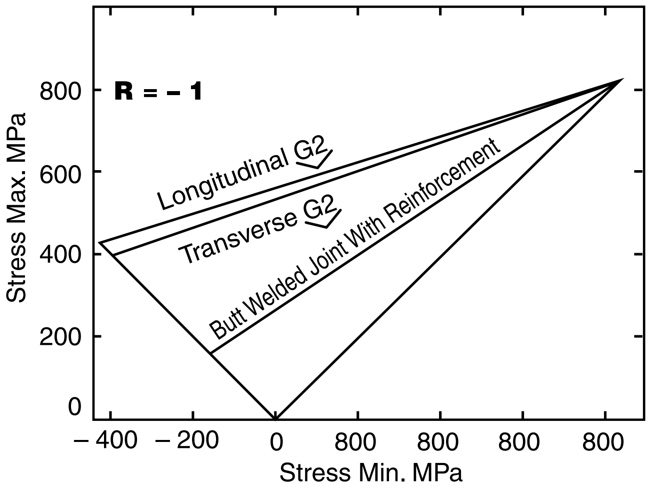
return to contents next page

6.6.3 Abrasion Resistant Grades

These grades are primarily employed because of their high hardness, and the influence of welding on plate hardness is of fundamental importance. Provided appropriate procedures are employed, the softening which invariably occurs in a region of the HAZ can be minimised, with little or no deleterious effects on subsequent service behaviour. The specific effects of welding on plate hardness in any practical situation will depend on many factors including choice of consumable, total weld heat input, weld geometry and proximity of adjacent welds. Refer to your consumable or material suppliers for further guidence.



S-N Curve for a AS 3597 Grade 700 Steel Parallel to Rolling Direction



Goodman Diagram Endurance Curves for a AS 3597 Grade 700 Steel at 2 X 10^6 Cycles Fatigue Strength

Figure 12 – Typical Fatigue Test Data for an AS 3597 Grade 700 type Steel.[12]

return to contents
next page

BIBLIOGRAPHY

1. Khruschov MM. Proceedings of the Conf. on lubrication and wear, Lond. Inst. of Mech. Engr., 1957, pp. 655-659.

2. Arasive Wear – 1965. Report of the iron and steel technical committee, SAE, New York, 1966.

3. Gardner FJ. The springback of metals. Trans. ASME, 1957, pp. 1-9.

4. Bunge Industrial Steels Pty. Ltd. Springback Testing of Bisalloy 80, 1982.

5. Cooperative Research Centre (CRC) for Materials Welding and Joining – unpublished results.

6. Bisalloy Steels Limited. The end use implications for Bisplate coated with a Polymer film to prevent flash rusting. Report BIS 95/004.

7. Ito Y and Bessyo K. Journal of Japan welding society, 1968, pp. 983-991.

8. Suzuki H. IIW Doc. IX-1074-78, 1978.

9. Suzuki H. Yurioka N and Okumura M. IIW Doc. IX-1195-81, 1981.

10. Suzuki H. IIW Doc. IX-1311-84, 1984.

11. High Strength Steels for Pressure Vessels. Nippon Steel Corp., 1977.

12. Bunge Industrial Steels Pty. Ltd. Fatigue tests on Bisalloy 80, 1982.

13. Bunge Industrial Steel Pty. Ltd. Flux cored arc welding of Bisalloy 80, 1981.

14. Bunge Industrial Steel Pty. Ltd. Gas metal arc welding of Bisalloy 80, 1982.

15. Bunge Industrial Steel Pty. Ltd. Submerged arc welding of Bisalloy 80, 1982.

16. Nippon Steel Corp. High strength and abrasion resistant Wel-ten Steels, 1983.

17. Bisalloy Steels Pty. Ltd. – Unpublished results.

18. Bisalloy Steels Pty. Ltd. Technical manual, 1992.

Welding Consumable Selection

Generic welding consumable selection tables were described in Table 4 of Chapter 6 and are similar to those which appear in Australian Standards such as AS/NZS 1554.4. To assist fabricators further in this selection process, some examples of Australian designations are shown in Table A.1 and AWS designations in Table A.2.

It is important to note that these tables are examples only and therefore are not exhaustive. Consumables other than those listed may be suitable in this application. Contact the consumable manufacturer for a complete listing.

Table A1 – Welding Consumable Selection Guide for Q&T Steels (AS Classifications)

0.2% Proof Stress (AS 3597)			500 MPa	600 MPa	700 MPa	Abrasian Resistant Grades (320-500 HB)
MMAW Consumables[1] **Warning:** Only use hydrogen controlled consumables						
	STRENGTH LEVEL	Matching	E5518-C1	E7618-M*	E7618-M	N.R.
		Lower	E4816-XHx X	E5518-C1	E5518-C1 / E6218-M	E5518-C1
		Lower	E4818-XHx X	E4816-XHx X / E4818-XHx X	E4816-XHx X / E4818-XHx X	E4816-XHx X / E4818-XHx H
	HARDNESS	Matching	N.R.	N.R.	N.R.	1430-A4, 1855-A4**
GMAW Consumables[2]						
	STRENGTH LEVEL	Matching	ESD2-GM-W559AH	ESM2-GM-W699AH	ESMG-GM-W769XH	N.R.
		Lower	ES4-GM-W503AH	ESD2-GM-W559AH	ESM2-GM-W699AH	ES4-GM-W503AH
		Lower	ES6-GC-W503AH	ES4 / ES6	ESD2-GM-W559AH	ES4-GC-W503AH
	HARDNESS	Matching	N.R.	N.R.	N.R.	1855-B6**
FCAW Consumables[3]						
	STRENGTH LEVEL	Matching	ETP-GMp-W554ANi1H_{10}	ETD-GCp-W769AK4H_5*	ETD-GCp-W769AK4H_5	N.R.
		Lower	ETP-GMn-W504ACM1H_5	ETP-GMp-W629AK2H_{10}	ETP-GMp-W629AK2H_{10}	ETP-GMn-W554ANi1H_5
		Lower	ETP-GMp-W503ACM1H_5	ETP-GMp-W554ANi1H_{10}	ETD-GMp-W554ANi1H_{10}	ETP-GMp-W504ACM1H_{10}
		Lower	ETP-GNn-W503ACM1H_{15}†	ETP-GNn-W503ACM1H_{15}†	ETP-GNn-W503ACM1H_{15}†	ETP-GNn-W503ACM1H_{15}†
	HARDNESS	Matching	N.R.	N.R.	N.R.	1430-B5, 1855-B5, 1860-B5**
SAW Consumables[4]						
	STRENGTH LEVEL	Matching	ECNi-FML-W554A.Ni2H_{10}	ECF5-FBL-W765AF5Hx*	ECF5-FBL-W765AF5Hx	N.R.
		Lower	EM12K-FGH-503A	EM12K-FGH-503A	EM12K-FGH+503A	EM12K-FGH-503A
		Lower	EL12-FMM-W404A	EL12-FMM-W404A	EL12-FMM-W404A	EL12-FMM-W404A
	HARDNESS	Matching	N.R.	N.R.	N.R.	1855-B1&B4**

Notes
1. MMAW – AS/NZS 1553.1-1995 and AS 1553.2-1987 consumable classification
2. GMAW – AS 2717.1-1984 consumable classification
3. FCAW – AS 2203-1990 consumable classification
4. SAW – AS 1858.1-1996 and AS 1858.2-1989 consumable classification

X = A variable – any
† This consumable is a self-shielded type
* Consumables overmatches strength requirement
** AS 2576 and WTIA TN 4 classifications
N.R. Not recommended

Table A2 – Welding Consumable Selection Guide for Q&T Steels (AWS Classifications)

0.2% Proof Stress (AS 3597)			500 MPa	600 MPa	700 MPa	Abrasian Resistant Grades (320-500 HB)
MMAW Consumables[1] **Warning:** Only use hydrogen controlled consumables						
	STRENGTH LEVEL	Matching	E8018-C1	E11018-M*	E11018-M	N.R.
		Lower	E7016-XHX X	E8018-C1	E8018-C1 / E9018-M	E8018-C1
		Lower	E7018-XHX X	E7016-XHx X / E7018-XHX X	E7016-XHx X / E7016-XHx X	E7016-XHx X / E7018-XHx X
	HARDNESS	Matching	N.R.	N.R.	N.R.	1430-A4, 1855-A4**
GMAW Consumables[2]						
	STRENGTH LEVEL	Matching	ER80S-D2	ER100S-G	ER110S-G	N.R.
		Lower	ER70S-4	ER80S-D2	ER100S-G	ER80S-D2
		Lower	ER70S-6	ER70S-4 / ER70S-6	ER80S-D2	ER70S-4 / ER70S-6
	HARDNESS	Matching	N.R.	N.R.	N.R.	1855-B6**
FCAW Consumables[3]						
	STRENGTH LEVEL	Matching	E81T1-Ni1	E110T5-K4*	E110T5-K4	N.R.
		Lower	E71T5	E91T1-K2	E91T1-K2	E81T1-Ni1
		Lower	E71T-5	E81T1-Ni1	E81T1-Ni1	E71T-5
	HARDNESS	Matching	N.R.	N.R.	N.R.	1430-B5, 1855-B5, 1860-B5**
SAW Consumables[4]						
	STRENGTH LEVEL	Matching	F8A4-ECNi2.Ni2	F11A5-ECF5*	F11A5-ECF5	N.R.
		Lower	F7A2-EM12K	F7A2-EM12K	F7A2-EM12K	F7A2-EM12K
		Lower	F6A2-EL12	F6A2-EL12	F6A2-EL12	F6A2-EL12
	HARDNESS	Matching	N.R.	N.R.	N.R.	1855-B1&B4**

Notes
1. MMAW – AWS A5.1-91 and AWS A5.5-81 consumable classification
2. GMAW – AWS A5.18-93 and AWS A5.28-79 consumable classification
3. FCAW – AWS A5.20-79 and AWS A5.29-80 consumable classification
4. SAW – AWS A5.17-89 and AWS A5 23-90 consumable classification

X = A variable – any
* Consumable overmatches strength requirement
** AS 2576 and WTIA TN 4 classifications. There are no equivalent AWS classifications.
N.R. Not recommended

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 1-96 – 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 2-97 – 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 3-94 – 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 4-96 – 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.

Flame Cut Surface Replicas

These have been developed to complement Technical Note Number 5 by defining three qualities of flame cut surface. Each set of three is contained in a convenient holder with a summary sheet of main flame cutting data.

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.

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.

return to contents next page

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.

return to contents