WTIA Technical Note No. 11

Commentary on the Standard AS/NZS 1554 Structural Steel Welding

Part 1:	Welding of steel structures	2004
Part 2:	Stud welding (steel studs to steel)	2003
Part 3:	Welding of reinforcing steel	2002
Part 4:	Welding of high strength quenched and tempered steels	2004
Part 5:	Welding of steel structures subject to high levels of fatigue loading	2004

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

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EXPERT TECHNOLOGY TOOLS for the Welding Industry

What are they?

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

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

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

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

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

What is Total Welding Management

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

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

Knowledge Resource Bank

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

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

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

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

Total Welding Management for Industry Sectors

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

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

How to Access ETTs

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

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

ETTs created by the WTIA are listed on page ?? 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 (Notes 1 and 2)

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 (incl. 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 (incl. Sub-Contracting)			
10. Production and 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 Steel TN9 Welding Rates in Arc Welding 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 AS 1674.2
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. ETTs can be formatted in a range of media.
Note 2: Dates and titles for the ETTs listed can be obtained from WTIA or SAI.

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This Technical Note:

- Is an Expert Technology Tool developed as part of the very successful WTIA National Diffusion Networks Project (NDNP), supported by industry and Federal, State and Territory Governments;
- Is a revision of the 1980, 1992 and 1998 editions of Technical Note 11 and includes comment on the editions of AS/NZS 1554 Parts 1 to 5 current at the date of publication. The Technical Note will be revised from time to time and comments aimed at improving its value will be welcomed;
- Is intended to complement the Standards and is referenced by them;
- Presents background material which could not be included in the Standards;
- Discusses the requirements of the Standards, with particular emphasis on new or revised clauses;
- Endeavours to explain the application of the Standards to welding in steel construction;
- Emphasises the need for the principal, design engineer, fabricator and inspecting authority to rely on the provisions of the Standard to achieve the required weld quality;
- Serves as an educational text for students of engineering;
- Has been prepared by WTIA and the Australian Steel Institute under the direction of WTIA Technical Panel 2 Metallurgy of Steels and WTIA Technical Panel 6 Steel Structures, and Standards Australia Committee WD-003.

Acknowledgments

WTIA wishes to acknowledge the contribution of its members, members of WTIA Technical Panels and Committees, WTIA SMART Industry Groups and all those in industry who have contributed in various ways to the development of this Expert Technology Tool.

Acknowledgement is given to editor Mr Bruce Cannon of BlueScope Steel Limited and Chairman of Standards Australia Committee WD-003.

WTIA wish to also thank Mr E Derwort from Bradken, Mr A Syam from Smorgon Steel Tube Mills, Mr J Ward from the Steel Reinforcement Institute of Australia and Mr A Williams from Stud Welding NZ for their assistance in the preparation of this edition of the commentary, and the staff of the Heavy Engineering Research Association (HERA) for review of the New Zealand specific contents.

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INTRODUCTION

The joint Australian/New Zealand Standard AS/NZS 1554 Structural Steel Welding was written to provide for safe, lowest total life cost of welded steel structures by our internationally competitive industry. The Standard can be trusted as written, is approved by all national regulators and is reliable in competent hands.

Whilst the Standard was written to be understood within the context of each of its parts, this commentary has been prepared by the Standard's writers and industry specialists as an aid and supporting document to generate better understanding in the application of the Standard to welding in steel construction. Since the Standard is written in the form of a technical specification, it cannot present background material or discuss the drafting subcommittee's intent; it is the primary aim of this commentary to fulfil this function.

Suggestions for the application, as well as clarification, of the requirements of the Standard are offered with specific emphasis on new concepts and sections that may be less familiar to the user. It should be recognised that the fundamental premise of the Standard is to provide general requirements applicable to any situation and thus leave sufficient latitude for the exercise of engineering judgement for each particular application.

To enable easy cross-referencing of clauses in the Standard with the commentary, the form of the commentary has been selected such that where a comment on a clause in the Standard is made, the same numbering sequence is adopted e.g. comment on clause 4.7.1 of Part 1 of the Standard is referred to by item A4.7.1 of the commentary. The letter prefix distinguishes between the clauses of different parts of the Standard e.g. clause 2.1 of Part 1 becomes commentary item A2.1 whereas clause 2.1 of Part 2 is commentary item B2.1. Where additional comment is made, but not directly to a clause in the Standard, the commentary uses a reference number not in the Standard e.g. B6.0 of the commentary is used for general comment on testing requirements of finished stud welds.

It is important that this Technical Note be read in conjunction with the Standards involved.

In Australia, AS 1250 (covering working stress design methods) on which AS/NZS 1554.1 was originally based, has been superseded by AS 4100 (covering limit state design methods) although for some specific applications, AS 1250 has been retained in modified form as AS 3990 (note that some authorities have retained specific reference to AS 1250, and as such, comments applicable to AS 3990 in this commentary apply also to AS 1250).

It is expected that AS 3990 and AS 4100 will co-exist for some time and both codes are referred to in this Technical Note. Due to its comprehensive nature, if AS 4100 is the relevant Standard in any structural design then sections of that Standard relative to welding should take precedence over AS/NZS 1554.1.

In New Zealand, AS 1250:1981 was the recognised working stress design method, adapted to New Zealand conditions by NZS 3404:1989. This 1989 edition of NZS 3404 also covered strength design (the predecessor of limit state design). Both were superseded by, firstly, NZS 3404:1992, and now, NZS 3404:1997, which covers, principally limit state design. The 1997 edition also covers working load design (i.e. dealing with working design actions rather than stresses). Some provisions in NZS 3404.1:1997 Appendix D relating to weld inspection take precedence over the corresponding provisions of AS/NZS 1554.1.

Additionally, the limit states version of the Australian/New Zealand Standard Cold Formed Steel Structures AS/NZS 4600 was released in late 1996. This Standard supersedes AS 1538 which was previously used in Australian and New Zealand practice and utilised the working stress design method. AS/NZS 4600 refers to AS/NZS 1554.1 for particular weld types and parent metal thicknesses.

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Scope

This commentary is to be read in conjunction with the appropriate part of AS/NZS 1554. The clause numbering in this document mirrors the AS/NZS 1554 part except for clauses starting XO-X which are general commentary.

The AS/NZS 1554 series of Standards Parts 1 to 5 covers the welding of steels for all non-pressure vessel or pipeline applications. The Standards are based on a series of common concepts whose significance must be understood if users are to obtain the maximum benefit in terms of product reliability and reduced manufacturing costs. The various parts of the Standard series were published at different times and this note deals with the following editions current at the time of publication. All are now joint Australian and New Zealand Standards.

- AS/NZS 1554.1-2004 Welding of Steel Structures. Dealing with statically loaded structures to a maximum material yield strength of 500 MPa and those subjected to moderate levels of fatigue loading.
- AS/NZS 1554.2-2003 Stud Welding (Steel Studs to Steel).
- AS/NZS 1554.3-2002 Welding of Reinforcing Steel.
- AS/NZS 1554.4-2004 Welding of High Strength Quenched and Tempered Steels dealing with the use of high strength steels both statically loaded and over the full range of fatigue loading permitted by AS 3990 and AS 4100.
- AS/NZS 1554.5-2004 Welding of Steel Structures Subject to High Levels of Fatigue Loading. Dealing with the special requirements of welds in materials up to 500 MPa yield strength subjected to fatigue loading higher than allowed under AS/NZS 1554.1 to the maximum allowed by AS 3990, AS 4100 and NZS 3404.1.

The various parts of the Standard have been revised and updated with commonality and simplicity in mind. Specifically, the clause numbers used in, for example, Part 1 are essentially the same as that used in Parts 4 and 5, making the application of the specific parts more user-friendly. The more important factors in the changes to the AS/NZS 1554 series are:

- the introduction of the GTAW process and procedures as prequalified in Part 1, 4 and 5;
- the revised method of preheat calculation used in Part 1 has been introduced to Part 5;
- the pre-qualification requirements of weld preparations has been expanded in Parts 1, 4 and 5;
- the use of pre-qualification of weld preparations and consumables to reduce qualification testing has been continued with the extension and clarification of consumable pre-qualification to FCAW in Parts 4 and 5;
- the revision of welder qualification requirements; and,
- updating the changes in Australian steel Standards.

The current range of the various parts of AS/NZS 1554 provide a rational system of controlling the full range of steel fabrication for structural purposes (including machinery) undertaken in Australian and New Zealand industry and provide a powerful impetus to improving both economics and reliability of welded steel fabrication.

In addition to the above five parts, AS/NZS 1554.6 was issued in 1994 and applies specifically to the welding of Stainless Steels. Whilst it is essentially based around a number of the above parts, caution should be exercised in extending the comments in this Technical Note to Part 6 as the corrosion and weldability implications of such comments must be considered. The reader is instead referred to WTIA Technical Notes 13 and 16 which provided the foundation for Part 6 of AS/NZS 1554 (at the time of revising this note, Technical Note 16 was scheduled for revision to incorporate a commentary relating specifically to Part 6).

In Australia, it should be noted that, while AS 4100 (Steel structures design Standard) will eventually replace AS 3990, both Standards will run in parallel for the short term (AS 3990 is predominantly used for the design of mechanical equipment such as cranes). During this time clause 9.7 (Design of Welds) in AS 4100 would take precedence over AS/NZS 1554.1 when working with AS 4100 as distinct from AS 3990.

Further, notation in AS 3990 and AS 4100 is different in some areas and the relevant standard should be checked.

In New Zealand, NZS 3404.1 is the sole Steel Structures Standard. New Zealand users should be aware of its provisions as it does contain a number of requirements that supersede those of AS/NZS 1554.1 e.g.:

- the mandatory approval of the welding procedure by the Principal; and,
- the suggested frequency of weld inspection given in Appendix D of NZS 3404.1.

TERMINOLOGY

Essentially this commentary uses the same terminology as that in the Standard, and in particular the terms and definitions of fabricator, principal, inspecting authority, inspector as follows:

Fabricator – the person or organisation responsible for the welding of the structure during fabrication and/or erection (fabrication includes cutting, and forming).

Principal – the purchaser or owner of the structure being fabricated or erected, or his nominated representative (e.g. the design engineer).

Inspection Authority – the building authority having statutory powers to control the design and erection of buildings or structures. Where the structure is not subject to statutory jurisdiction, the principal (or his designate e.g. the design engineer) is deemed to be the inspecting authority.

Inspector – a person employed by or acceptable to the inspecting authority for the purpose of inspecting welding in accordance with this Standard.

This commentary makes frequent specific reference to the responsibility and functions of the following persons or groups, which for the purposes of this commentary are defined as:

Welder or Operator – the person who performs the welding operation

Stud Manufacturer – the person or organisation responsible for the manufacture and supply of prequalified studs for arc stud welding.

For the purpose of the commentary, the welding process names and definitions given in AS 2812 apply, with the following abbreviations:

Process	Abbreviation	Other Common Names
Manual Metal Arc Welding	MMAW	SMAW (used in Europe and USA)
Gas Metal Arc Welding	GMAW	MIG or MAG
Flux Cored Arc Welding	FCAW	
Gas Tungsten Arc Welding	GTAW	TIG
Submerged Arc Welding	SAW	
Electroslag Welding	ESW	
Consumable Guide Welding	ESW-CG	
Electrogas Welding	EGW	
Stud Welding	SW	

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SECTION A: PART 1 – WELDING OF STEEL STRUCTURES

A0 Guidance In The Use Of Part 1 – Welding of Steel Structures

A0.1 Guidance for the Design Engineer

A0.1.1 General

The essential requirement of a weld is that adequate service performance is provided. Usually a variety of alternative methods of achieving this aim are available, and it is the most economical of these methods which should be used.

The principal considerations in achieving economical weldments have been detailed elsewhere (Reference. 3) and the following specific guidance relates to obtaining the most economical result from Part 1.

1) The weld category (General Purpose(GP) or Structural Purpose (SP)) appropriate to the weld joint should be used and guidance on selecting weld categories for particular applications is given below in section A0.1.2. At all times, a "fitness-for-purpose" philosophy should be adopted and over-specification of weld category avoided. Consequently, in terms of pure welding economics, a blanket philosophy of all welds being category GP unless specified otherwise would seem appropriate. However, this must be balanced by the designer rigorously noting all higher specification SP category welds - this weld category generally being in a higher proportion of welds than the GP category weld for most structures. Such design specifications would be dependent on client expectations, design contract conditions and the associated fee structure.

2) Reliance on the provisions of Part 1 to achieve the desired result without writing special requirements or individual clauses into the specification is recommended.

3) The level of non-destructive examination and visual inspection should be appropriate to the application, and guidance on appropriate levels on non-destructive examination is given in Table A0.1.2.

4) The design engineer should not specify joint preparation or welding procedure, but rather leave the selection of these to the fabricator so that the most economical combination is utilised.

5) Steel quality should not be over-specified (i.e. notch toughness tested steels should be used only where they are necessary). The guidance given in Appendix B of Part 1 is entirely adequate for the purpose of avoiding brittle fracture. Note that the fabricator should be advised of the design service temperature to assist the appropriate selection of welding consumables (see section A4.6.1).

6) Use standardised details wherever possible (Reference. 4).

7) Do not specify unnecessary welding. For example, do not have general notes which state: 6mm continuous fillet weld all round.

8) Avoid unnecessary post-weld processing, such as weld cleaning and dressing by grinding.

9) It is most desirable that the design engineer and fabricator interact so as to ensure that the purpose of the design, its overall function and any special requirements are communicated. If a fabricator suggests a modification leading to possible improvements, evaluate the suggestion with an open mind.

10) Seek specialist advice when in doubt.

11) Go through the checklist of matters for discussion; this will prevent unnecessary confusion and save cost in the end.

12) It is of vital importance that the drawings or other information provided to the fabricator clearly indicate:
    a) size of weld or where full penetration welds are required
    b) weld category
    c) method and extent of NDE.

Experience with the use of AS/NZS 1554.1 has shown that ambiguity on these points is the major cause of dispute between designer and fabricator.

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A0.1.2 Guidance in the Use of Part 1 for Typical Applications

As indicated below in section A1.1, the Standard may be used for a wide variety of applications, these being summarised in Table A1.1 (a).

Suitable weld categories (typical but not definitive) for these applications are given in Table A0.1.2. As well, suggested methods and levels of inspection are given for guidance only. Recognition that compliance with the requirements of the Standard by the fabricator will achieve the desired assurance of quality will minimise the need for non-destructive examination beyond that recommended.

In considering the method and level of inspection which might be employed in a particular application, the design engineer, whose responsibility it is to select both method and level of inspection, must have regard to the level of stress and the nature of the application involved.

As the stress level increases, it is not unreasonable to expect an increase in the level of inspection although it should be noted that based on the method used (e.g. ultrasonic or radiographic methods), increased levels of inspection are more costly.

The level of inspection selected should be varied in a sensible manner throughout a particular contract. For example, if an overall 10% of all welds are to be examined by radiography, it would be wise to begin with a higher level of inspection of, say 25% of all initial welds including a minimum of one weld of each welder, until it is established that the welding is being done satisfactorily and dropping this off to random spot check as a quality control tool if the welding remains satisfactory. An overall level of 10% approximately can be achieved by suitable manipulations. If imperfections outside the values permitted in Part 1 are encountered, it would again be wise to increase the level of inspection until satisfactory welds are again produced.

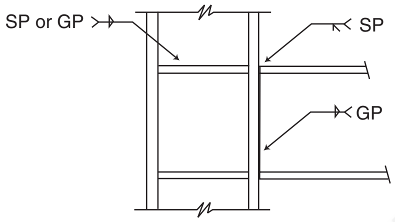


Figure A0.1.2 (a) Welded beam-to-column moment connection

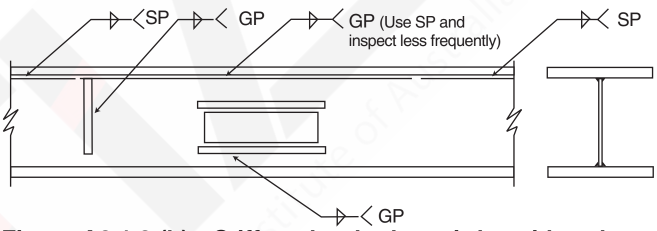


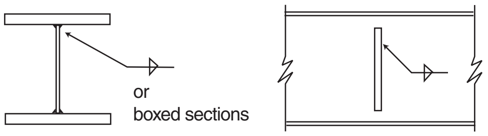
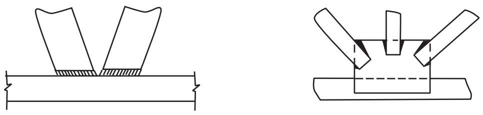
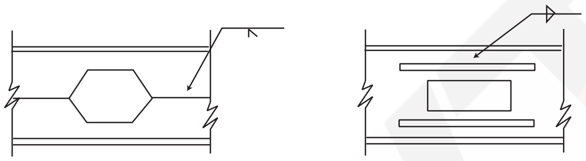
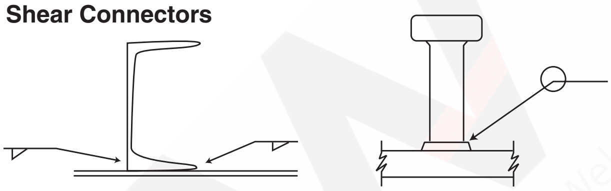
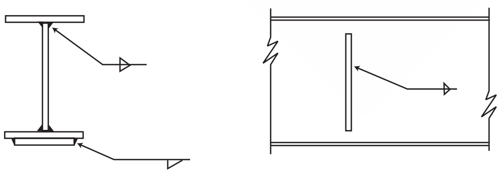
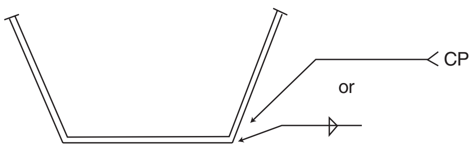
Figure A0.1.2 (b) Stiffened web plate girder with web penetration

Table A0.1.2 – Suggested Applications of Weld Categories

Applications	Typical Weld Category	Suggested Methods of NDE[1,2]	Suggested Levels of NDE[1,2]
AISC Standardised Structural Connections (Reference 4)			
(Welded) Angle Seat – Fillet Welds	SP	Visual	25-50%
Bearing Pad – Fillet Welds	SP	Visual	25-50%
(Welded) Flexible End Plate – Fillet Welds	SP	Visual	25-50%
(Welded) Web Side Plate – Fillet Welds	SP	Visual	25-50%
(Welded) Beam to Column Moment Connection, (Welded) End Plate Connection, Welded Splice, Column Base Plate: Butt Welds in Flange/Web*	SP	Visual	25-50%
Fillet Welds in Flange	SP	Visual	25-50%
Fillet Welds in Web	SP	Visual	25-50%
Fillet Welds on Erection Cleat	GP	Visual	10-25%
Purlin and Girt Cleat	GP	Visual	10%
Bracing – End Connections	SP	Visual	25-50%
Column Stiffeners – for rigid connections	SP/GP	Visual	25%
* For butt welds in the flange where seismic design is involved or where a plastic hinge may form at the connection	SP	Visual and Ultrasonics/Radiography	100% 10-25%
Typical Application for GP Category Welds: Handrailing, Carport columns and beams, Stairs and Ladders, Gates and doors, Catwalks and walkways, Steel house frames, Lightly loaded support brackets and cleats	GP	Visual	0-25%

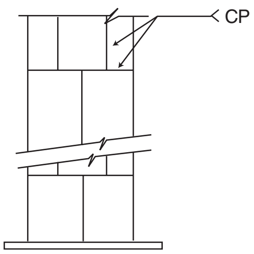
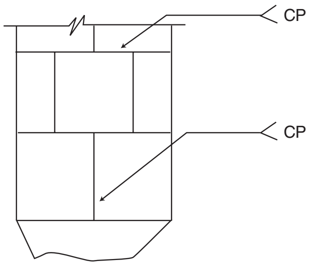
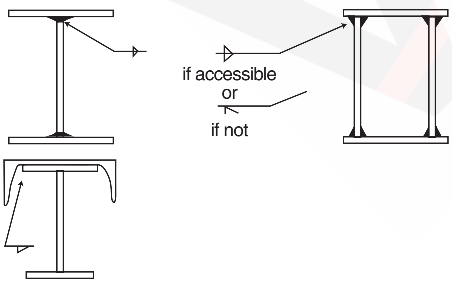
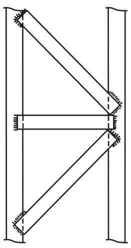
1. The suggested levels of visual inspection, magnetic particle, liquid penetrant, radiography or ultrasonics are in addition to 100% visual scanning (see Table 7.4).
2. The use of magnetic particle or liquid penetrant testing is used to a limited extent for supplementary inspection after visual inspection (see Table 7.4)..

Table A0.1.2 – Suggested Applications of Weld Categories – *continued*

Applications	Typical Weld Category	Suggested Methods of NDE[1,2]	Suggested Levels of NDE[1,2]
Buildings – Connections other than those in AISC Standardised Structural Connections			
– Static Loadings, No Fatigue			
Web to Flange Fillet Weld	GP or	Visual	0-10%
	SP		10-25%
Intermediate Stiffeners – Fillet weld	GP	Visual	0-10%
Load Bearing Stiffeners – Fillet Weld	GP or	Visual	0-10%
	SP		10-25%
			
Butt Welded Splices in Plates	SP	Visual	25-50%
Truss Connections – either fillet welded or butt welded	SP	Visual	25-50%
			
Castellated Beams – Butt Welds in Web	GP	Visual	10-25%
Web Penetrations in Beams – Welding of Stiffeners	GP	Visual	10-25%
			
Shear Connectors 	SP	Visual	10-25%
Bridges			
Web to Flange Fillet Weld	SP	Visual	25-50%
Cover Plate Fillet	SP	Visual	25-50%
			
Intermediate Stiffeners – Fillet Weld	GP/SP	Visual	10-25%
Load Bearing Stiffeners – Fillet Weld	SP	Visual	10-25%
Welded Splices in Plates – Butt Welds	SP	Visual and	50-100%
		Ultrasonics/Radiography	0-20%
Corner Butt Welds in Box Girders	SP	Visual and	50-100%
		Ultrasonics/Radiography	0-10%
			
Field Welded Butt Splices in Girders	SP	Visual and	100%
		Ultrasonics/Radiography	100%

1. The suggested levels of visual inspection, magnetic particle, liquid penetrant, radiography or ultrasonics are in addition to 100% visual scanning (see Table 7.4).
2. The use of magnetic particle or liquid penetrant testing is used to a limited extent for supplementary inspection after visual inspection (see Table 7.4).

Table A0.1.2 – Suggested Applications of Weld Categories *– continued*

Applications	Typical Weld Category	Suggested Methods of NDE[1,2]	Suggested Levels of NDE[1,2]
Chimneys, Tubular Masts Butt Welds – Joining Plates – At Base  	SP SP	Visual and Ultrasonics/Radiography	25-50% 0-5%
Tanks, Bins, Bunkers, Hoppers Butt Welds – Joining Plates, Vertical – Joining Plates, Horizontal Welds at Cone – Cylinder Transition  	SP SP/GP SP	Visual and Ultrasonics/Radiography Visual Visual and Ultrasonics/Radiography	25-50% 0-5% 25-50% 50-100% 0-10%
Cranes – Crane Beams, Crane Runway Girders Web to Fillet Weld or Butt Weld Gantry Girders – Fillet Weld Connection Channel to Beam Intermediate Web Stiffeners or Diaphragms – Fillet Weld Load Bearing Stiffeners – Fillet Weld Weld Splices in Plates – Butt Welds  	SP SP GP/SP SP SP	Visual Visual Visual Visual Visual and Ultrasonics/Radiography	25-50% 25-50% 10-25% 10-25% 50-100% 0-20%
Cranes – Crane Jibs Fillet Welds (including battened members) 	SP	Visual	50-100%

1. The suggested levels of visual inspection, magnetic particle, liquid penetrant, radiography or ultrasonics are in addition to 100% visual scanning (see Table 7.4).
2. The use of magnetic particle or liquid penetrant testing is used to a limited extent for supplementary inspection after visual inspection (see Table 7.4).

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Weld categories can be mixed on a project but should not be mixed along a weld. For example:

(i) In Figure A0.1.2(a) it would be quite in order in a welded beam-to-column moment connection to have SP weld category for the flange butt welds, but either SP or GP for the fillet welds along the web or for the fillet welds along the column stiffeners.

(ii) In Figure A0.1.2(b) the web-flange fillet welds in a three-plate girder may have stress levels which vary along the beam such that an SP category weld may be required at the ends of the beam, while GP category welds are sufficient elsewhere. Obviously, in this case, an SP category weld should be specified for the full length, but more weld inspection should be concentrated at the ends of the beam. If a length of weld which does not comply with SP category was found in the central position, it could still be accepted if it complied with GP category. It would, however, be quite in order to specify GP category welds for intermediate web stiffeners or stiffening around a web penetration.

Care should be taken when mixing categories as described above as inspection time increases due to the fact that the GP category welds need to be clearly distinguishable from the SP category welds and thus the inspection level effectively increases to 100% as the inspector must ensure that GP welds have not been used in areas nominated for SP category welds.

For the selection of weld categories for seismic design refer to section 13 of AS 4100 or clause 9.7.1.4 of NZS 3404.1.

A0.2 Guidance for the Fabricator

Part 1 is based on the concept that structural steel fabrication can most effectively be done by the establishment of routine welding procedures which are judged against realistic quality standards. The maximum benefits in the use of Part 1 will only be gained by organisations prepared to develop and adhere to welding procedures which are both productive and tolerant to minor variations in parameters which inevitably occur in practice. The aim of the fabricator must be to develop a library of qualified procedures, appropriately documented, which will be acceptable to principals with little or no further qualification testing and which can be employed by the fabricator's welding staff as a matter of routine.

Prior to commencing fabrication it is most important to ensure that weld category, full penetration welds and type and extent of NDE are agreed with the client. Whilst it is not unreasonable to adopt category GP where weld category is not specified (i.e. the minimal position), this should always be verified and not assumed as required under Appendix D of Part 1 (Matters for resolution). It is safer for the fabricator to assume the SP position if doubt exists as under normal circumstances SP quality welds are well within the capability of an average welder/tradesman (the primary difference between GP and SP quality is the level of inspection recommended and defect acceptance levels).

Part 1 lists prequalified welding consumables and prequalified joint preparations, which may be employed with very little pre-production qualification testing, which are intended to yield satisfactory welds under conditions of normal levels of workmanship. The aim of the fabricator should therefore be to develop more productive techniques particularly through:-

a) the use of narrower welding grooves;
b) the use of increased root faces;
c) elimination of back gouging; and,
d) the use of multi-wire techniques and electroslag welding.

Many of these alternatives are dependent upon accuracy of the edge preparation and fit-up, and the extent to which an individual fabricator is prepared to devote attention to these matters will dictate the extent to which advantage may be taken of more productive welding techniques. For the purposes of internal quality control, the fabricator should establish somewhat tighter limits of welding parameters than are required in Part 1. It must be pointed out that the voltage and current measuring instruments normally fitted to welding equipment are notoriously unreliable and inaccurate (even when calibrated, they can be unreliable – note the warning given in WTIA Technical Note 19 clause 5.11.2), and it is strongly recommended that a fabricator set welding procedures against calibrated instruments especially kept for the purpose, and which are used to calibrate machine meters used in production (see A4.11). In the case of welding processes employing gas mixtures for shielding, it may also be desirable to adopt similar measures for the measurement of gas flow rates.

To ensure consistent quality of welding, it is also important for the fabricator to ensure that welding procedures are used as required by the Standard. Such checks should be documented as they provide evidence to both the principal and Quality Auditor that the procedures are being followed.

Attention is drawn to the extensions of procedure qualification which are possible using Tables 4.11(A), 4.11(B) and 4.11(C). A fabricator should endeavour to minimise the amount of procedure qualification, for example by using item (i) in Table 4.11(A), which allows a number of weld runs to be increased in proportion to the joint thickness without re-qualification. Clauses 4.1.2 and 4.1.3, and Item (o) of Table 4.11(A) permits procedure qualification to be further extended beyond the thickness of the procedure qualification test piece.

Although procedures qualified to SP category may be employed without further testing on GP category welds, it may often be the case that, owing to the generous level of permissible imperfections for GP category welds, back gouging may be eliminated. Procedures qualified for use on notch toughness tested materials may be employed, without further qualification testing, on materials with lesser notch toughness testing requirements (e.g. a procedure qualified for use on a steel impact tested at -15°C can be used on a steel impact tested at 0°C but not vice

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versa). Procedures developed for high Weldability Group Number materials can be used on lower Group Number steels but these alternatives will not necessarily lead to the most productive techniques. Careful consideration should be given to employing high heat input procedures, such as multi-wire SAW and ESW, on non-notch toughness tested material, and in every case welding parameters should be set to eliminate the need for preheat.

The fabricator should also balance the costs of surface preparation, such as removing paint, against the increased productivity in terms of welding rates obtainable with bare metal surfaces, since Part 1 does not require surface preparation as such, but merely requires that procedures be qualified on the surfaces to be employed in production.

A0.3 Guidance for the Inspector

The provisions of Part 1 in respect of welding procedures and workmanship are such that satisfactory welds should be achieved as a matter of course. In keeping with this philosophy, the inspector's role is to ensure that the requirements of Part 1 are followed so that the relatively low levels of weld inspection envisaged by the Standard may be applied successfully in practice. This role also includes checks (documented) to ensure that the welding procedures required by the Standard are being correctly used and followed (e.g. using a calibrated tong tester or external meters to verify the welding parameters in use against those indicated in the procedure).

The main objective of Part 1 is to produce welded steel structures which are economical to fabricate and serviceable for the intended application. It does not strive after unattainable and unnecessary perfection. The welding inspector should continually remember that the repair of minor imperfections which do not endanger the performance of the structure is undesirable and such repairs not only substantially increase the cost of fabrication but may also reduce the serviceability of the structure through the introduction of excessive residual stresses and distortion. The inspector's attention is therefore drawn to both clause 6.7 of Part 1 and section A01.2 above.

A0.4 Guidance for the Welder

Welding requires a high level of manipulative skill on the part of the welder. The role of the welder is very important for the success of fabrication and in achieving the desired weld quality. Mistakes in welding can be expensive both in business and safety terms.

AS/NZS 1554.1 requires that welds be made in accordance with a qualified welding procedure and by welders appropriately qualified to do so. Specific instructions relevant to the welder and applicable to a particular weld are provided in this document. The welding procedure specification document (WPS) identifies the essential welding variables and the level of control required to produce sound welds. The welder should review each element of the welding procedure, any special instructions and testing requirements.

The Standard also contains a series of workmanship provisions common to all welding operations. Customer specifications and contract documents such as drawings may also contain additional workmanship provisions in excess of the Standard's provisions and these need to be identified before welding commences and incorporated into the final weldment. Listed below are the general welding practices which when followed are instrumental in obtaining the sound weld metal deposits required to ensure the quality fabrication of structural steel.

(a) Cleaning: All surfaces to be welded should be smooth and free from oxide, paint, grease and moisture. Rust-inhibiting coatings, weld-through primers and anti-spatter compounds that do not interfere with weld quality or the welding operation may remain (see also section A5.1 of this Technical Note). The surfaces must be smooth and free from fins, tears, cracks and other discontinuities. Cleaning may be accomplished by shot/sand blasting, grinding, wire brushing or chemical cleaning. All flux and/or slag adhering to a layer of weld metal must be completely removed prior to depositing the next bead or pass unless qualified otherwise. For example some welding consumables such as metal cored wires leave a thin slag film on the surface of the weld which can be readily welded over, however there may be a limit to layers of weld that can be applied in this manner before affecting weld quality. The electrodes, filler wires and fluxes must be prevented from contamination with rust, oil, grease, etc. They should be stored in accordance with the manufacturer's recommendations in all cases. This information is readily available from welding consumable manufacturers.

(b) Fit-up: Joint fit-up as required to maintain drawing and qualified welding procedure dimensions can be accomplished by the use of jigs & fixtures, tack welds, temporary clamps, strong backs, braces, jacks, etc. Alignment of parts to be welded will at times have very significant effect on fatigue performance of the weld. Therefore misalignment of the components must be minimised. The weld groove dimensions as fit-up should be within permissible tolerance. AS/NZS 1554.1 permits the rectification of fit-ups not conforming to the procedure by welding and grinding.

(c) Tack welding: It is important that the surface to be tack welded is cleaned as recommended above as surface contamination increases the possibility of cracks and lack of fusion in the tack welds. All tack welds are required to be of the same quality as the final weld (including preheat temperature control requirements). They should therefore be sound, full throated welds, essentially free from undercut and deep craters. The Standard requires a minimum length of tack weld at least 4 times the thickness of the thicker part in the joint or 40mm, whichever is the longer.

(d) Preheating: Where preheating is specified, the parent metal adjacent to the intended weld should be heated above the minimum specified temperature and maintained above the temperature till welding is completed. As a guide, a minimum width of 75 mm

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or the thickness of the plate, whichever is greater, is required to be raised above the specified preheat temperature. Where preheat is specified for the weld, all tack welds wether to be incorporated in the final weld or not, are required to comply with the same preheat requirements. Preheat should be checked with temperature indicating crayons, infrared thermometer, contact pyrometer or other suitable measuring equipment. Normally plates are heated one side (often the bottom side) and preheat temperature checked on the other side of the plate. Preheat should be applied in such a manner to avoid high thermal gradients that may occur when using oxygen-fuel gas cutting torches. The preferred method of application is by is air (or oxygen) fuel gas heating burners or electric resistance heating providing a slow thorough soaking of preheat through the section thickness.

(e) Welding: The welder should always refer to the applicable WPS and take note of any special instructions, prior to starting the welding.
- Weld starts and stops at the ends of the joint are to be performed in a manner that would ensure sound welds. Use run-on and run-off tabs when required to minimise the presence of start and stop regions.
- Arc strikes outside the area of the weld on the parent metal should be avoided. Areas affected by arc strikes should be examined for cracks using suitable NDE methods. Cracks detected should be completely removed and the repaired area re-examined.
- A good ground (return) connection is essential for sound welds.
- Any defective condition, such as, porosity, lack of fusion, uneven bead, etc. should be removed before depositing subsequent runs.
- The weld reinforcement should be controlled within specified limits.
- Welding should not be abruptly stopped at corners. The weld bead should be taken around the edge of the plate so that the crater is away from the corner in a lower stressed region of the joint.
- Multipass welds should have the ends cascaded or at least in different locations.

(f) Quality: All welds should be visually examined by the welder to ensure that weld quality requirements are met. Visual examination should address items such as weld size and amount of reinforcement, freedom from excessive undercut and porosity, and the removal of all slag and spatter. Wherever non-destructive examination (NDE) is called for, the weld joint should be cleared at the sub-assembly stage before proceeding with further assembly.

A1 Scope and General

A1.1 Scope

Part 1 covers all items relevant to the welding of steels, dealing in turn with:-

- Section 2 – Materials of Construction: selection of parent material; backing material; electrodes and filler wires; flux; shielding gas.
- Section 3 – Details of Welded Connections: butt welds; fillet welds; compound welds; seal welds; plug and slot welds; welds for the purpose of combining rolled steel sections.
- Section 4 – Qualification of Welding Procedures and Personnel: qualification of welding procedure; method of qualification; prequalified welding procedures; prequalified joint preparations; qualification of welding consumables; qualification by testing; extension of qualification; combination of processes; records of tests; re-qualification; qualification of welding personnel.
- Section 5 – Workmanship: preparation of edges for welding; assembly; preheating; welding under adverse conditions; tack welding; weld geometry; distortion; correction of faulty welds; temporary attachments; arc strikes; cleaning; dressing.
- Section 6 – Quality of Welds: categories; methods of inspection and permissible levels of imperfection; radiography; ultrasonic examination; magnetic particle examination; liquid penetrant examination; weld defects; reporting.
- Section 7 – Inspection: qualifications of the inspector; visual inspection of work; non-destructive examination other than visual examination.

Part 1 applies to the welding of steels in fabricated weldments used in applications such as those discussed in A1.1, using the following welding processes listed in clause 1.1:-

a) Manual metal arc welding (MMAW)
b) Submerged arc welding (SAW)
c) Gas metal arc welding (GMAW)
d) Gas tungsten arc welding (GTAW)
e) Flux cored arc welding (FCAW)
f) Electroslag (including consumables guide) welding (ESW)
g) Electrogas welding (EGW)

The welding processes included under (a) to (g) are the common processes used for virtually all weldments in Australia and New Zealand at present. Specific provisions (for example prequalified weld preparations) relevant to each process are included where necessary.

AS/NZS 1554.1 is intended to be complementary to any application Standard or specification for the design and construction of welded steel fabrications. Part 1 was originally written for the welding of steel structures conforming to AS 1250 - now AS 3990, but its provisions are generally applicable to a wide range of steel weldments. Part 1 is also applicable to structures conforming to AS 4100 or to NZS 3404.

It should be noted that AS 1538 has been superseded by AS/NZS 4600 for cold-formed steel structures. The former Standard was presented in working stress format and the latter is in limit states format. AS/NZS 4600 also refers to AS 4100 for the calculation of design capacities for arc welded connections where each of the connected parts is greater than or equal to 3mm thickness, or 2.5mm thick for fillet welds. Welding is to be undertaken to AS/NZS 1554.1 (or other parts of AS/NZS 1554 as appropriate) in those situations. For parent metal thicknesses less than noted above, welding is to be done in accordance with ANSI/AWS D1.3.

Typical applications for which the Standard may be used are listed in Table A1.1 (a), while specific applications which are excluded are listed in Table A1.2.

The Standard specifically includes within its scope all statically loaded welded joints, as well as most welded joints subject to fatigue loading. Fatigue stress categories B, C, D, E and F of AS 3990 are covered for the full maximum permissible stress range given in AS 3990. The maximum stress ranges which fall within the limits of Part 1 are given in Table A1.1 (b).

The rationale for the exclusion of the 80-100% region of maximum permissible stress range for fatigue stress categories A and B is given in A1.6.

AS/NZS 1554.1 Category SP welds comply with the fatigue requirements of AS 4100 or NZS 3404.1 for Detail Categories 112 and below.

Table A1.1 (a) Typical applications for AS/NZS 1554.1

Nature of Application	Typical Application	Application Standard
Building Frameworks	Welded connections including: beam-to-column beam-to-beam bracing cleats and attachments compound members member splices base plates	AS 4100 AS 3990 NZS 3404
Cranes	Welded connections in overhead travelling cranes, crane jibs, monorail beams	AS 1418, AS 4100, AS 3990 and NZS 3404
Road and Pedestrian Bridges	Welded connections including those for making compound members, welding of stiffeners, welding of cleats and attachments	Australian Bridge Design Code (Reference 1), AS 4100 and NZS 3404
Rail Bridges	as for road bridges	Australian Bridge Design Code (Reference 1), NZS 3404
Chimneys, Stacks, Masts and Towers	Welding of wall plates, strakes, base connections, stiffeners	Nominated in contract
Tanks	Welding of liquid storage tanks including wall plates, base connections and stiffeners (**Note:** For low temperature applications, Appendix B may be used for some wall thicknesses and steel types for temperatures down to minus 40°C)	Nominated in contract
Bins and Bunkers	Welding of bulk storage bins and bunkers, including wall plates, details, connections, stiffeners, compression ring, supports	Nominated in contract
Machinery, Mine Headers, Mine Winders, Frameworks for mechanical Plant and Machinery	Welding of connections	AS 4100 AS 3990 NZS 3404
Ships	Welding of plates, details and attachments, stiffeners	Nominated in contract
Conveyors, etc	Welding of support gantries	AS 4100, AS 3990 and NZS 3404
Roof Structures, including Grandstands	Welded connections	AS 4100, AS 3990 and NZS 3404
Cold Formed Members (relevant to above applications)	Welded connections except those made by resistance welding	AS/NZS 4600

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Table A1.1 (b) Maximum Permissible Stress Ranges - for Application of AS/NZS 1554.1 to AS 3990

Fatigue Stress Category (FSC)	Maximum Permissible Stress Range, Fsr, MPa							
	Loading Condition 1 Fsr1		Loading Condition 2 Fsr2		Loading Condition 3 Fsr3		Loading Condition 4 Fsr4	
	SP	GP	SP	GP	SP	GP	SP	GP
A	410	*	245	*	165	*	165	*
B (Note 2)	310 (248)	**	185 (148)	**	120 (96)	**	110 (88)	**
C	220	44	130	26	85	17	65	13
D	185	37	110	22	65	13	45	9
E	140	28	85	17	55	11	30	6
F	100	20	80	16	60	12	55	11

Notes to Table A1.1 (b):

1. Loading conditions 1, 2, 3 and 4 (i.e. Fsr1, Fsr2, Fsr3 and Fsr4) are described in Table B1 of AS 3990.
2. Fatigue Stress Category (FSC) A refers to a base metal with rolled or cleaned surfaces and the Maximum Permissible Stress Range (MPSR) for this FSC is listed under "SP" for convenience of tabulation.
3. The values listed in the Table for SP category welds are 100% of the MPSR values given in Table B3 of AS 3990.
4. For FSC B, the values given in the bracket ( ) are based on 80% of the MPSR given in Table B3 of AS 3990. For FSC B stress ranges larger than the bracketed term and below the SP listed term, welds to AS/NZS 1554.5 should only be specified.
5. The columns headed "SP" apply for SP weld category.
6. The columns headed "GP" are suggested as being suitable for GP weld category. It is suggested in A1.6 that GP welds might still be used in applications where some cyclic loading is involved, provided that the stress range is less than 20% of the values given in Table B3 of AS 3990. The values listed under the GP weld category in the Table are those 20% values.

   * FSC A refers to the base metal only and is irrelevant for the GP weld category (see Note 2 also).

   ** For FSC B, most of the practical weldments in this category are generally loaded more than 50% of the maximum permissible stress (see A1.6) and, hence, is also not considered for the GP weld category.

Note: There is no similar table in AS 4100 and that Standard should be referred to when it is the relevant Standard.

The design engineer faced with design situations involving fatigue stress category B of AS 3990 or fatigue categories above 112 in AS 4100 or NZS 3404.1 can adopt one of two approaches:-

(i) by suitable placement of welded joints, keep the maximum stress range below the values given in Table A1.1 (b), use SP weld category and weld to the provisions of Part 1; or

(ii) specify welding in accordance with AS/NZS 1554.5

It is recommended that option (i) be exercised wherever possible.

AS 3990 has been used as the reference Standard from which the levels of permissible imperfections for SP and GP weld categories have been set.

Part 1 only applies where brittle fracture is not a design consideration (section A2.1). Specifically, it is based on the assumption that it is possible to design out of potential brittle fracture problems by using the information given in Appendix B of Part 1. Consequently, weld categories SP and GP have been allocated permissible levels of imperfections in the knowledge that the resultant welds will not be used in an application where brittle fracture is a concern.

If clause 2.1 and Appendix B are not followed in all respects, then the application is outside the scope of Part 1. For such a case, if the possibility that the weld could be used in an application where brittle fracture is of concern, then a higher quality of weld than SP, with much more restrictive permissible imperfections, is required (e.g. AS/NZS 1554.5).

Specialist advice should be sought in such cases.

Lamellar tearing is not mentioned in clause 1.1, nor in any other clause of Part 1, largely because it is substantially avoided through appropriate design practices and only occurs when the coincidence of high restraint in a welded joint combines with insufficient through-thickness ductility in the steel. Whilst most steels currently manufactured in Australia and New Zealand have minimal susceptibility to lamellar tearing due to improved steel making practices, such problems can still be encountered where high restraint stresses or through-thickness stresses are known to occur. In these circumstances, steel can be purchased with guaranteed through-thickness ductility (generally known as 'Z' type steels). In the absence of any guidance in Part 1 as to acceptable levels of defects resulting from lamellar tearing, it is suggested that the plate edge defect rules in the AWS Structural Steel Welding Code AWS D1.1 (section 5.15.1) be used. For further information on lamellar tearing, please refer to WTIA Technical Note 6.

When welds are made to transfer principal stress through one member in the through thickness direction, any large inclusions in the steel near the fusion line may exceed acceptance criteria for weld imperfections (see section A6.7 of this commentary) and also interfere with ultrasonic examination. If this is assessed by the designer

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to be a significant risk to the structure, the designer should request ultrasonic examination of the critical areas of steel plates to level 1E of AS 1710 prior to the commencement of fabrication. The designer should then take account of the expected lower ductility and fracture toughness associated with fracture in the through thickness direction i.e. plane of the plate.

A1.2 Exclusions

The following welding processes are not covered by Part 1, but are not necessarily excluded from use in terms of Part 1:-

1) Oxy-fuel gas welding (GW)
2) Friction welding (FW)
3) Thermit welding (TW)
4) Resistance welding (RW)

All provisions of Part 1 can in fact be used to control welding by any of these or other processes including laser welding (not mentioned). However, specific provisions for their use are not included in Part 1 and therefore it is necessary to ensure compliance with recommended procedures and practices when such processes are used. The AWS Welding Handbook (Reference 6) provides good guidance, but agreement between the principal and the fabricator as to procedures and practices to be followed is necessary.

In the case of resistance welding of thin cold formed structures complying with AS/NZS 4600, it is specifically recommended that such welding be done in accordance with the requirements of the American Welding Society's AWS C1.1 or AWS C1.3 as appropriate.

Examples of applications specifically excluded from Part 1 are listed in Table A1.2. The other exclusions given in clause 1.2 are dealt with in this commentary separately as follows:-

(i) the limitation of 500 MPa for the yield strength of the steel to be welded; (A2.1)
(ii) design of welded connections and permissible stresses in welds; (A3.1.2)
(iii) the production, rectification or repair of castings; (A2.1)

A1.3 Innovation

The scope of Part 1 gives clear indication of where and how the Standard is to be applied in practice. In doing so, new materials, welding processes and/or consumables and methods of construction (including NDE methods) are not specifically excluded, with the fabricator being allowed to innovate provided that prior approval has been gained from the inspection authority.

A1.6 Weld Categories

The weld category should be selected by the design engineer on the basis of the stress level in the weld for the intended applications and is required to be designated on the drawings (see clause 3.1.3).

For each category of weld (GP or SP), maximum permissible levels of imperfections have been established (Tables 6.2 and 6.3) which will be adequate for the range of intended applications.

The wording of clause 1.5.2 regarding when weld category GP and SP should be used is to be considered as strongly advisory – but not mandatory. The design engineer has been deliberately left the option of stepping outside the guidelines given in this clause (and in clause 1.1 in the case of weld category SP).

It should be recognised that increased costs and production delays can arise due to over specification of the weld category (i.e. specifying a weld quality higher than SP) and is not recommended. In any case, weld category SP is sufficient for most applications. Wherever a higher weld quality than that provided by SP is required it must be specified in the tender documents.

The general design philosophy adopted in Australia has been weld category SP unless otherwise noted (Reference 2) whilst in New Zealand the recommended approach has been to use the general note "all welds shall be category GP unless specified otherwise" on all drawings and thus specifically mark all SP category welds on each drawing.

Table A1.2 Examples of Applications Excluded from AS/NZS 1554.1

Nature of Application	Details Excluded	Application Standard
Pressure Vessels	vessel, all welded details	AS 1210 AS/NZS 3992
Boilers	vessel, all welded details	AS 1228 AS/NZS 3992
Piping	all welded details	AS 3992 AS 4041 AS 4413
Pipelines	all welded details	– AS 2885
Reinforcement in Concrete Structures	all welded details	AS/NZS 1554.3 AS 3600
Stud Welding	all welded details	AS/NZS 1554.2 ABDC# AS 2327
Tanks	cryogenic applications	– –

Australian Bridge Design Code (ABDC) – Reference 1

The rationale for the selection of the intended range of application of each weld category is explained below.

In comparison with other codes or Specifications, weld Category SP is approximately equivalent to the quality of welding specified:-

(i) in an earlier edition of AS 1554 (Part 1 – 1974, Part 2 – 1974); and
(ii) in the AWS Structural Welding Code – Steel (AWS D1.1) for buildings.
(iii) the now withdrawn NZS 4701 weld class A.

For the information of the reader, the basic quality of welding required by AS/NZS 1554.1 was equivalent to the current SP category prior to the introduction of the SP and GP categories in 1980. In the 1980 edition, SP category was called 'special purpose' but this was changed to 'structural purpose' in 1985 where it has been retained to the current editions.

Note: *Weld category must always be clearly specified otherwise fabricators may assume the minimal position and work within the broader GP category requirements.*

Category SP

The SP weld category may be regarded as the standard full-strength structural weld, used with the reinforcement intact and without heat treatment. This weld category is considered adequate under dynamic load conditions for Detail Category 112 and below in AS 4100 or NZS 3404.1 and for the complete stress range for fatigue categories C, D, E and F and also for up to 80% of the stress range specified for category B in AS 3990. The value of 80% as an upper limit for category B was arrived at by examination of the relative effects of weld reinforcement and defects on fatigue performance, and applies principally where the required fatigue life is in excess of 2 x 10^6 cycles.

In New Zealand, reference should also be made to Parts 1 and 2 of NZS 3404 for seismic and fatigue requirements of category SP welds.

Category GP

The GP weld category is the less stringent in its requirements of the two weld categories specified in Part 1. It is intended for use in welded joints which are essentially statically loaded and it is suggested that this statement could be taken to mean that the actual stress range for some fatigue categories is less than 20% of the stress range permitted in AS 3990, AS 4100 or NZS 3404.1. Under static loading condition, GP category welds should only be specified where the calculated weld stress meets the requirements of AS 4100 or NZS 3404.1, or is less than 50% of the maximum possible stress specified in clause 9.8 of AS 3990. GP category welds will occur quite frequently in certain types of structures (see section A0.1). The design engineer should always endeavour to specify GP weld category where appropriate in order to take advantage of the less stringent qualification requirements, minimal testing and lower production costs associated with this weld category. Only under circumstances where a risk assessment indicates that weld failure could lead to severe consequences (including the loss of life), should a design engineer contemplate specifying as SP category those welds which could otherwise, according to these guidelines, be categorised as GP.

Both fillet welds and complete and incomplete penetration butt welds may be used in either weld category SP or GP.

A minor change to this section occurred in the 2004 edition of Part 1 with reference to AS/NZS 4600 in clause 1.6 being removed primarily because AS/NZS 4600 does not utilise either weld category.

A1.7 Basic Welding Requirements

The basis of the Standard is that the weld shall:-

a) be made in accordance with a qualified welding procedure;
b) be carried by a welder suitably qualified for that procedure (see section 4.11.2 of Part1); and
c) be carried out under the supervision of a welding supervisor who is employed by, or contracted to, the fabricator; and,
d) comply with the appropriate requirements of the Standard.

Under certain conditions set out in the Standard welding procedures may be deemed 'prequalified' meaning that the extent of testing required to qualify the procedure is limited (in some cases, no testing is required).

It is important to note that all of the above must be complied with at all times, otherwise non-destructive examination over and above that recommended in Clause 7.4 of Part 1 will be required, and, in the event of rejectable defects being found in the fabrication, it can be difficult to apply clause 6.7 permitting the use of fracture mechanics to limit the extent of repair.

The informative note referencing the use of AS/NZS ISO 3834 and its parts was added to this section in the 2004 edition as a recommendation, primarily to assist fabricators to meet their quality management obligations particularly when producing large, complex or critical structures, or when various fabrication activities require the approval of the Principal or Inspecting Authority whose focus may be more on the management of quality rather than actual specific fabrication tasks. Numerous problems have occurred in the fabrication of such welded structures that could have been prevented had welding related activities been appropriately managed.

A1.8 Safety

The 1995 and later editions lists the applicable safety standards. The requirement to identify and manage other hazards associated with welding was introduced in 2004 and is a consistent with the fabricator's obligations under occupational health and safety legislation and regulations.

A2 Materials of Construction

A2.1 Parent Material

The parent materials complying with the list of Standards given in the clause represent the most common steel types used in the structures and applications discussed in section A0:-

AS 1163	Structural steel hollow sections
AS 1397	Steel sheet and strip – Hot dipped zinc-coated or aluminium/zinc-coated
AS 1450	Steel tubes for mechanical purposes
AS 1548	Steel plates for pressure equipment
AS/NZS 1594	Hot-rolled steel flat products
AS/NZS 1595	Cold-rolled unalloyed low carbon steel sheet and strip
AS 2074	Steel castings
AS/NZS 3678	Structural steel – Hot-rolled plates, floor plates and slabs
AS/NZS 3679.1	Structural steel: Hot-rolled bars and sections
AS/NZS 3679.2	Structural steel: Welded I sections
NZS 3415	Hot-rolled products of non-alloy structural steels and their technical delivery conditions

Steels to other Australian Standards which could also be welded in terms of this Standard include:-

AS 1074	Steel tubes and tubular for ordinary service
AS 1442	Carbon steels and carbon-manganese steels: Hot-rolled bars and semifinished products
AS 1443	Carbon steels and carbon-manganese steels: Cold-finished bars
AS 1448	Carbon steels and carbon-manganese steels – Forgings (ruling section 300mm maximum)

This is not an exhaustive list. These steels may be welded in terms of Part 1 by making use of clause 1.2 which permits the use of materials and methods not specifically referred to in the body of the Standard.

Additional guidance on qualification requirements for non-prequalified steels was added to clause 2.1 in the 2004 edition of Part 1, primarily to assist with the usage of steels similar to but not necessarily identical to those listed. The use of all other steel types will continue to require the establishment of a satisfactory welding procedure in accordance with section 4 of Part 1. In particular, testing to the extent indicated in Table 4.7.1 and clause 4.7.1 is recommended to verify the procedure.

AS 2074 – Steel Castings is included as a complying Standard but only for the welding of such castings to the parent materials listed in clause 2.1. The production, rectification and repair of steel castings are covered by AS 1988 (see also WTIA Technical Note 18).

If the parent material is to be prime painted or galvanised before welding, the welding procedure must be qualified with parent material having the same surface coated conditions. If the procedure cannot be qualified under these conditions, the paint or galvanising must be removed in the vicinity of the weld (clause 5.1.1). This requirement also applies where anti-spatter fluids and compounds are applied to the weld preparation prior to welding.

The 500 MPa upper limit for the yield strength of the parent material was introduced in the 2000 edition of Part 1 to cater for high strength low alloy steels described in the materials Standards listed in clause 2.1(c). Designers should note though that a 450 MPa upper limit for the yield strength of the parent material remains in AS 3990, AS 4100 and NZS 3404.1. Higher strength quenched and tempered (Q&T) steels should be welded in accordance with AS/NZS 1554.4. The welding of stainless steels is excluded from the provisions of Part 1, AS/NZS 1554.6 being the appropriate Standard (additional guidance can also be found in WTIA Technical Note 16).

The reference in (b) of clause 2.1 to Appendix B ensures that, where brittle fracture is a design consideration, a steel with suitable notch ductility is selected for that application (see Appendix B of Part 1). The whole approach of Part 1 is based on the assumption that sufficient notch ductility is available in the parent material (see A1.1 above).

A2.2 Backing Material

In many applications, double-sided welding is not possible since there is no access to the root side of the joint. In such cases, complete penetration welding from one side may be done using either an unsupported root or, more simply, with the aid of backing material.

One-sided welding, especially where weldments cannot be turned, eliminates the need for difficult and time-consuming overhead welding. On corner butt welds requiring complete penetration welds, one-sided welding with backing materials eliminates welding with restricted access from the root side.

Permanent Backing Material

Permanent backing material is, by definition, steel and remains permanently in place. Such backing material usually consists of steel of the same material as the parent material and consequently meets the requirements of the clause automatically.

For static applications, the weld root of the one-sided weld may be formed by use of permanent backing material, which is a flat steel strip of sufficient proportions to support the molten pool during welding of the root run(s). The dimensions of the backing strip vary depending on the type of welding process, the size of the root gap or fit-up tolerance, the access at the root and the means of supporting the backing strip prior to welding.

The usual widths of steel strips used range from 25mm to 40mm depending on thickness and availability of bar stock. For low current GMAW (short arc welding) and MMAW, the minimum thickness recommended to prevent burn through is 3mm, although on long welds this thickness should be increased since distortion of the strip during welding of the root could result in excessive gaps and subsequent weld defects. For spray transfer GMAW, FCAW and SAW, a minimum backing strip thickness of 5mm is recommended. Where rear access is available to the backing strip, the strip may be mechanically dogged against the underside of the weld. Alternatively the strip may be tack welded (note clause 5.5) into position. In both cases the gap between the backing strip and either of the abutting components should not exceed 1.5mm (clause 5.2.4).

For fatigue applications, the notches at the parent material-backing material interface make this type of joint equivalent to an incomplete penetration butt weld for fatigue design purposes.

The clause requires that the backing materials shall have at least equivalent weldability to the parent material(s) being joined. The weldability of the parent materials covered by Part 1 are indicated on a relative basis by the Weldability Group Number assigned to each grade of steel in Table 5.3.4(A) of Part 1. To comply with the requirements of this clause, the Weldability Group Number of the backing material must be less than or equal to that of the parent material.

For example, backing material to AS/NZS 3678 grade 250 may be used as backing material for steel to AS/NZS 3678 grade 350 but the reverse situation (grade 350 backing material for 250 steel) is not permitted.

While the chemical composition or mechanical properties of the backing material need not match those of the parent material(s), a steel with Group Number 4 (or lower) is always recommended for permanent backing material (see Table 5.3.4(A) of Part 1).

Care should be exercised that free cutting steel grades (which contain additions of elements such as sulphur, lead etc.) which are readily available in bright bar form, are not used as backing strips. Backing strip material which is heavily rusted must not be used as it can cause porosity and other defects. Since moisture between the backing strip and the components may cause serious weld defects including hydrogen induced cracking, it is recommended that positioning and tacking of backing strips be performed immediately prior to the welding of the joint wherever practical. Alternatively, preheating to "dry the joint" is recommended (minimum preheat temperature of 60°C is recommended) especially where hydrogen controlled electrodes are employed. Care should be exercised during flame preheating with LP Gas as a fuel gas, since condensate from the flame may introduce moisture into the joint preparation.

Intermittent tack welds may be used in static applications to hold the back-up strip in place, but these welds must comply with clause 5.5 (including the preheat requirements of clause 5.3). In fatigue situations, permanent backing material should be avoided wherever possible, but if necessary the use of continuous fillet welds is recommended to hold the strip in place. In all instances, where backing strips are used, the procedure qualification should simulate the conditions which will apply on the job. In particular, the tack welding of the backing strip forms part of the procedure qualification. Any change in the type or detail of the backing system constitutes a change in procedure and re-qualification of the welding procedure is necessary by a macro test (Table 4.11(C), item (e) (iv) of Part 1).

Note: *The use of steel sections (e.g. round bars, reinforcing steel etc) other than flat strip or bars as permanent backing material is not recommended. The inappropriate use of such shapes as backing material is likely to cause weld penetration problems in particular and compromise the integrity of the structure. See also section A4.5 and similar comments on the use of fill bars.*

Temporary Backing

Temporary backing takes a variety of forms. Water cooled copper backing bars are frequently used in conjunction with automatic welding machines to enable a complete penetration butt weld without the need for turning, root gouging and root side welding. Air cooled copper backing bars are applicable over a wide range of welding situations, including field applications, but as is the case with other forms of temporary backing, the root may require dressing and even a sealing run to ensure that the finished weld meets the requirements of Part 1. When using copper backing bars, particular care should be taken to avoid copper pick-up into the weld metal, which may cause subsequent cracking. This usually requires a joint preparation which prevents direct impingement of the arc onto the backing bar.

Other forms of temporary backing include glass, flux, ceramic and refractory composites, and these may come in either rigid or flexible form in a wide variety of shapes. Some are designed to fit into metal supports which are then mechanically or magnetically held against the underside of the joint, while others are formed onto an adhesive strip which is simply stuck onto the weldment.

Where a corrosion problem is unlikely to arise, and especially where removal of the temporary backing is difficult, the backing material may remain in position, providing the approval of the principal or the inspecting authority is obtained.

Procedure qualification in all cases must be carried with the type of backing material to be used in production.

A2.3 Welding Consumables

A2.3.1 Electrodes and Filler Wires

Electrodes to AS/NZS 1553.1 (and AS/NZS 1553.2 as appropriate) are prequalified in terms of clause 4.6 (Table 4.6.1(A)). Other consumables may be used, but they must be qualified as provided in clause 4.6.2.

Covered electrodes for manual metal arc welding of structural steel grades encompassed by Part 1 are available in a wide range of sizes and coating types to suit different welding applications. Electrodes to AS/NZS 1553.1 and AS/NZS 1553.2 are branded with their classification (in the form EXXXX) to enable ready identification of electrodes from broken packets. It is the responsibility of the fabricator and the inspector to ensure that the correct electrodes (size and type) are being employed under the appropriate operating conditions (current and polarity).

Consumables for GTAW to AS/NZS 1167.2 are prequalified in terms of clause 4.6 (Table 4.6.1 (a)). Other consumables may be used, but they must be qualified as provided in clause 4.6.2.

Consumable electrodes for semi-automatic or automatic processes of GMAW and FCAW are solid or tubular wires. Electrodes for FCAW to AS 2203.1 are prequalified (clause 4.6) but other electrodes may be used provided they are qualified under clause 4.6.2. GMAW electrodes to AS/NZS 2717.1 are prequalified.

Electrodes for SAW to AS 1858.1 as well as certain electrodes for the other welding processes with appropriate ship classification societies approval are also prequalified (clause 4.6). Other electrodes may also be used provided they can be qualified under clause 4.6.2.

It must be noted that at all times electrodes and consumables must be used within the manufacturer's specified limits. Use outside of these limits automatically voids their compliance with the original qualification (as determined by the manufacturer) and as such, must be requalified under the provisions of clause 4.6.2.

A2.3.2 Care of Electrodes and Filler Wires

Some types of covered electrode coatings are prone to moisture pick-up which may adversely effect the running characteristics of the electrode (unstable arc, excessive spatter, arc blow) and introduce defects into the weld (porosity, hydrogen cracks). The clause therefore requires that electrodes be stored in their original packets or cartons (broken or sealed) in a dry place (before and during use). In the case of hydrogen controlled electrodes, it is the fabricators responsibility to ensure that electrodes are stored and conditioned in accordance with the electrode manufacturer's recommendations.

WTIA Technical Note 3 provides guidance and recommendations for the correct storage and conditioning of welding consumables.

Filler wires, both solid and flux cored, are required by Part 1 to be "dry, smooth and free from corrosion or other matter deleterious either to satisfactory operation or to the weld metal". Filler wires which have obviously deteriorated in condition, to the extent that surface rust is clearly visible, should be discarded. Dulling of the copper coating or staining of the uncoated wire surface may not necessarily constitute a reject consumable.

A2.3.3. Flux

A flux to AS 1858.1, in combination with a prequalified electrode, is prequalified under clause 4.5. In relation to storage and conditioning of fluxes for SAW and guides for ESW-CG, the same comments made in regard to coatings on MMAW electrodes apply.

A2.3.4 Shielding Gas

Shielding gases for GMAW and FCAW welding of the parent materials within the scope of Part 1 are usually one of the following:-

a) CO_2: Carbon di-oxide is especially suited to short-arc welding (short circuiting or dip transfer mode) with solid wires at low current, although this shielding gas also finds general usage in higher current welding using both solid and flux-cored wires. CO_2 is a low cost gas providing deep and broad penetration. Under certain conditions it may give rise to relatively high levels of spatter. In order to avoid the loss of an effective gas shield, heaters should be installed on CO_2 gas supply regulators to prevent freezing up.

b) Argon: Welding grade Argon is not generally used for the GMAW and FCAW welding of the steel grades listed in clause 2.1 of Part 1.

c) Gas mixtures, consist generally of welding grade Argon (Ar) base with additions of CO_2 (up to about 25%), oxygen (O_2 – up to about 10%) or both. Argon based gases containing Helium (He) additions are also available. These gases find specific application with both solid and flux cored wires to provide spray transfer at high current, however they are also suitable for dip and globular transfer. Characteristics are high deposition rates, deep finger penetration and smooth, spatter free weld appearance.

Inert gases such as welding grade Argon or Helium are normally used as a shielding gas for the GTAW welding of parent materials within the scope of Part 1.

In 2003, Standards Australia released AS 4882 to cover the classification of shielding gases used for welding. Accordingly the reference to the –35°C dew point limitation (approximately 220ppm of moisture by volume in the gas) was replaced by referencing AS 4882 in the 2004 edition of Part 1. Dew point limitations continue to apply through AS 4882 so that excessive water in the gas will not cause freezing in the regulator or contribute to weld metal hydrogen. It should be noted though that, whilst all shielding gases for welding manufactured in Australia and New Zealand are proprietary mixes, suppliers normally guarantee to meet the requirements of AS 4882 and its dew point restrictions. This should be verified by the fabricator by consulting with the gas supplier.

Since the type of shielding gas has a fundamental influence on metal transfer and operation of the process, a change in gas classification may require re-qualification of the welding procedure (see section A4.11). On the other hand, the procedure qualification is not affected by a change in supplier of the shielding gas, provided the same gas classification within the composition limits specified in AS 4882 is supplied (see A4.11).

A3 Details of Welded Connections

A3.1 General

A3.1.3 Drawings

The information listed in clause 3.1.3 must be provided to the fabricator either on the contract drawings or in the specification to enable him to assess what he is required to do in any given contract.

The information which must be provided is as follows:-

(a) Specification and grades of parent metal
(b) Nominal tensile strength of weld metal (f_{uw}) (see AS 4100, NZS 3404 and AS 3990)
(c) Location, type, size of weld, and effective length of all welds
(d) Whether welds are to be made in the shop or at the site
(e) Weld category
(f) Details of non-standards welds
(g) Details of seal welds if such welds are required
(h) Type and extent of inspection, including any special inspection requirements
(i) The relevant design standard
(j) Any special requirements which would affect welding operations

For example, the information may be provided in:-

(i) general notes on drawings – e.g. items (a), (b), (i) and possibly (e), (h)
(ii) connection details – e.g. items (c), (d), (e), (f), (g), (h)
(iii) the specification – e.g. items (h), (j)

Whilst it is of vital importance that all of the above information is provided by the design engineer, it should be noted that there are considerable benefits to the fabricator if at the very least items (a), (b), (e), (f), (h), (i) and (j) are appropriately and clearly indicated on all drawings. Reference 2 provides some guidance on information for engineering drawings of structural steelwork in commercial building construction.

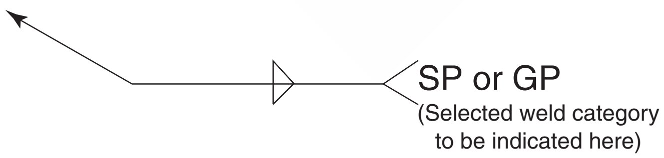

Figure A3.1.2 Indication of Weld Category on Drawings

The location, type, size and effective length of a weld can be indicated using the welding symbols of AS 1101.3. The weld category could be indicated at the location shown in Figure A3.1.3

Note: *AS 1101.3 (see Figure 12.1) also provides guidance for non destructive examination symbols and for the location of such symbols on the drawings. This systematic approach of itemising NDE test method and the extent of testing to be used for a particular joint can be very useful when the structural performance of particular joints is of importance.*

The position recommended in Figure A3.1.3 for the weld category designation is the position normally reserved for specification items including any process, procedure or reference requirements. The welding procedure specification may occasionally appear on shop detail drawings (but generally not on engineers' drawings) and if so, the shop detailer needs to incorporate both pieces of information.

Two notable items deliberately not included in the list of clause 3.1.3 are:-

(i) type of welding process to be used;
(ii) type of edge preparation for butt welds;

These rightly are the province of the fabricator, to be selected by him.

A3.2 Butt Welds

A3.2.1 Size of Weld

The intention of clause 3.2.1. is indicated in Figure A3.2.1 below.

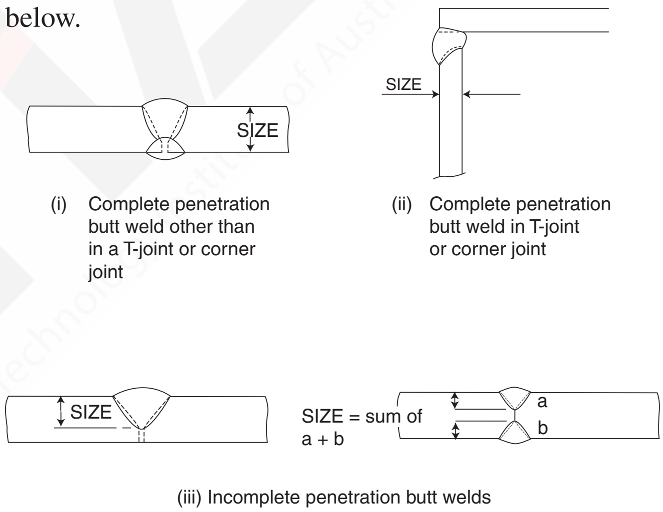

Figure A3.2.1 Size of Butt Welds

Clause 3.1.3 requires the size of weld to be specified on the drawings. This presents no problem in respect of complete penetration butt welds, where the term complete penetration butt weld or the appropriate symbol from AS 1101.3 guarantees the desired result. In the case of incomplete penetration butt welds however, the design engineer determines the design throat thickness (clause 3.2.2.), while the size is a function of:

(i) the design throat thickness;
(ii) the welding process;
(iii) the details of the weld preparation.

In lieu of specifying the size of an incomplete penetration butt weld, the drawings should show the required design throat thickness. This then allows the fabricator to produce the design throat thickness by selecting a suitable weld preparation, welding process and welding position. This is particularly important in the case where a fully automatic welding process is to be used, as clause 3.2.2.2 (c) permits some advantage to be gained due to the deep penetration usually achievable.

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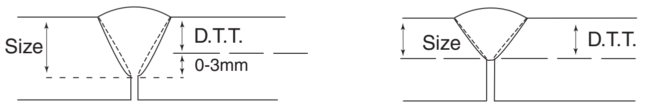
A3.2.2. Design Throat Thickness

The design throat thickness is defined in AS 2812 as "the minimum dimension of throat thickness used for purposes of design" and is distinct from the actual throat thickness.



(i) Incomplete penetration butt weld made by other than fully automatic process

(ii) Incomplete penetration butt weld made by fully automatic process

Figure A3.2.2 Design Throat Thickness

The definitions in the clause for complete penetration butt weld and incomplete penetration butt weld are self explanatory.

For prequalified incomplete penetration butt welds shown in Table E2 of Part 1, designers and fabricators alike should be aware that depending on the weld joint selected, the prequalified design throat thickness (*DTT*) may vary with welding process and extra depth of weld may be required to achieve the *DTT* e.g. for joint B-P5, *DTT* is $(D_1 + D_2)$-6 for the MMAW process and $D_1 + D_2$ for the SAW process.

In the case of fully-automatic arc welding processes, clause 3.2.2.2 (c) permits advantage to be taken of the penetration achievable with such processes to reduce the size of the weld deposited, provided a macro test demonstrates the viability of the procedure (Figure A3.2.2).

A3.2.3. Effective Length

The length of a "continuous full size weld" is not necessarily the actual weld length. In certain cases, it is necessary to use "run-on" and "run-off" tabs to ensure that a full size is present at the ends of a weld. Otherwise the effective length may be reduced below the actual length.

A3.2.5 Transition of Thickness or Width

Where plates subject to tension are varied in thickness or width or both, the required smooth transition can be made by the methods given in Figure 3.2.5 of Part 1. The maximum slope of 1:1 is a mandatory upper limit for either thickness or width transition of plates in tension, although smaller slopes may be chosen, usually at some cost penalty. Some fatigue situations in AS 3990, AS 4100, NZS 3404 and the Australian Bridge Design Code (Reference 1) do require lesser slopes and clause 3.2.5 makes clear that this lesser slope must be observed. Some seismic applications also require a more gradual transition as given in NZS 3404.

It should be observed that, in general, the lesser the slope the greater the cost due to difficulties in preparation. Excessively low slopes on thickness transitions may need to be machined, which can be very costly.

The maximum slope of 1:1 is in contrast to the maximum slope of 1:2.5 required in section 2.20 of AWS D1.1.

Note: *Some AS 4100 and NZS 3404 fatigue categories nominate a maximum taper of 1:4. Similarly, ISO 10721.1 also nominates a maximum slope of 1:1 for general structural welding and for fatigue categories, a maximum slope of 1:4 is allowed.*

The rationale for the 1:1 transition is related to the equivalent stress raising effect of weld defects and reinforcement permitted by Part 1 for both GP and SP category welds (see Tables 6.2 and 6.3 of Part 1). A gradual transition is of little practical use if notches and stress concentration effects prevail adjacent to and in the weld.

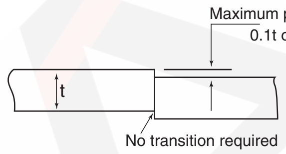


Figure A3.2.5.1 Permissible Offset of Abutting Plates

The 1:1 maximum slope is a general provision for detailing of the weld. For butt welds in equal thickness plates, an anomaly presents itself since an offset of abutting plates is allowed of up to 0.1t or 3mm, whichever is the lesser in clause 5.2.2 (see Figure A3.2.5.1). The requirement of clause 5.2.2. governs in such cases and the 1:1 maximum slope requirement of clause 3.2.5 is waived.

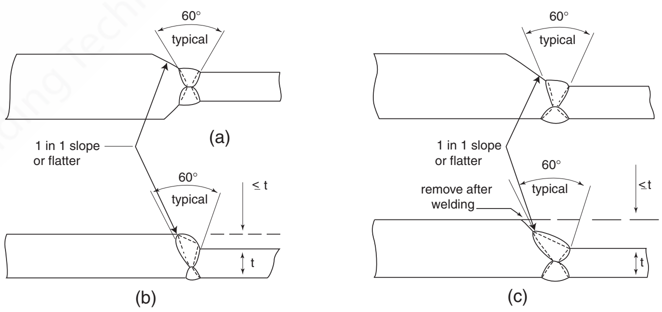


Figure A3.2.5.2 Transition in Thickness Between Unequal Members

Thickness transition

Depending on whether the adjoining plates have centreline or offset alignment, Figure 3.2.5 (a) of Part 1 illustrates the various methods of achieving the required transition. When a large difference in thickness exists, there is little option but to prepare the plates to be joined with a special edge preparation. This will usually require a flame cut or machined edge with multiple faces as shown in Figure A3.2.5.2 (a).

Where the offset or thickness differential is less than the thickness of the thinner part connected, the transitions may be achieved by sloping the weld to the top surface of the thinner plate (Figure A3.2.5.2 (b)). The weld crown should blend with the transition slope to avoid a sharp notch at the toe between the weld surface and the slope.

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Alternatively, the weld may be sloped to the prepared face of the thicker member (Figure A3.2.5.2 (c) with subsequent sloping of the unfused top edge. The methods illustrated in Figures A3.2.5.2 (b) and (c) are most practical and economic since they permit conventional edge preparations to be cut on the plates prior to welding operations.

Width transition

Figure 3.2.5 (b) of Part 1 illustrates the recommended method for transition of butt joints in parts of unequal width by chamfering the wider part with the slope of the chamfer not being steeper than 1:1.

A3.3 Fillet Welds

A3.3.1 Size of Weld

The definition of fillet weld size comes directly from AS 2812 and is adequately illustrated in the diagrams within Table E3 of Part 1 wherein symbol S is the size (the leg length).

Note: *Australian and New Zealand practice is to denote the size of fillet welds by the leg length while European practice is to use the throat dimension. Users should be wary of this when using European drawings and specifications.*

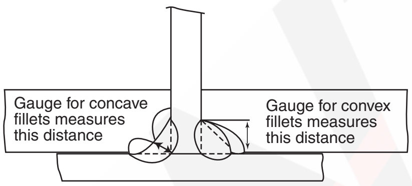

Figure A3.3.1 Measuring the Size of Fillet Welds

Convex fillet welds may be measured with a gauge of type shown on right; in this case it measures the leg size. Concave fillet welds are measure with a gauge like the one on left; in this case it measures the weld throat.

Preferred fillet weld sizes have the advantage of setting a standard size range for design engineers to work to, and are sizes measurable with the available fixed fillet weld gauges, the usage of which is illustrated in Figure A3.3.1. There is no restriction implied on using other non-preferred sizes.

The measured size should not be less than that specified on the drawings. The amount of reinforcement permitted on convex fillet welds of SP category is limited by Table 6.2.2 of Part 1, and for concave fillet welds the size may be reduced up to a maximum loss of cross-sectional areas of 5% for SP category welds and 10% for GP category welds (Table A6.2.2 of this commentary).

In specifying the size of fillet weld required, it is important to only provide the amount of welding needed to ensure that the welded joint can perform its intended function. The specification of oversize welds is to be discouraged, as is the "weld all round" philosophy, since both practices lead to unnecessary additional cost (Reference 3).

The economics of fillet welding should be kept in mind at all times. In the horizontal fillet positions, single run fillet welds are usually limited to a 6 or 8mm leg size for most processes (notably MMAW), although the other process, under certain conditions a 10mm or larger single run fillet is possible. If more than single run welding is required, the cost of the weld increases significantly (Reference 3).

Single run continuous fillet welds, which must meet the minimum size requirements of Table 3.3.5 of Part 1, are usually more economic than intermittent fillet welds of a larger size. However, continuous fillet welds may cause more distortion and sometimes intermittent welds with a planned sequence are used for distortion control.

A3.3.2 Design Throat Thickness

The figures referred to in the clause comply with the definition given in AS 2812.

In a similar manner to butt welds, advantage may be taken of the increased penetration achievable with a fully automatic welding process to reduce the size (but not the design throat thickness) of a fillet weld - 85% of the penetration being considered as part of the design throat thickness. The viability of the procedure must be demonstrated by means of a macro test.

One item that is a design matter, but which is included in Part 1, is the design throat thickness for skewed T-joints made using fillet welds. Table E3 of Part 1 gives a formula for such cases which is more accurate than the approximate formulae contained in previous editions of this Standard. Table E3 of Part 1 limits the angles to between 60° and 90°, which effectively covers the region of 60° to 120°.

It is usual practice not to rely upon fillet welds connecting members at angles outside the range 60°-120° to transmit calculated loads at the full maximum permissible stress given in the design Standard. Butt welds should be used in lieu of fillet welds in such cases.

A3.3.3 Effective Length

It is important to note that the effective length is the over all length of full-size fillet welds. Previous editions of this Standard required a deduction of twice the weld size from the actual length, but experience has proved that this provision is unnecessary.

The minimum effective length requirements of:-

(i) 4 times the fillet weld size; and

(ii) 40 mm;

for intermittent fillet welds are identical to the provisions given in AS 3990, AS 4100, NZS 3404 and in the Australian Bridge Design Code (Reference 1).

The requirements of AS 3990 for fillet welds are summarised in Figure A3.3.3.

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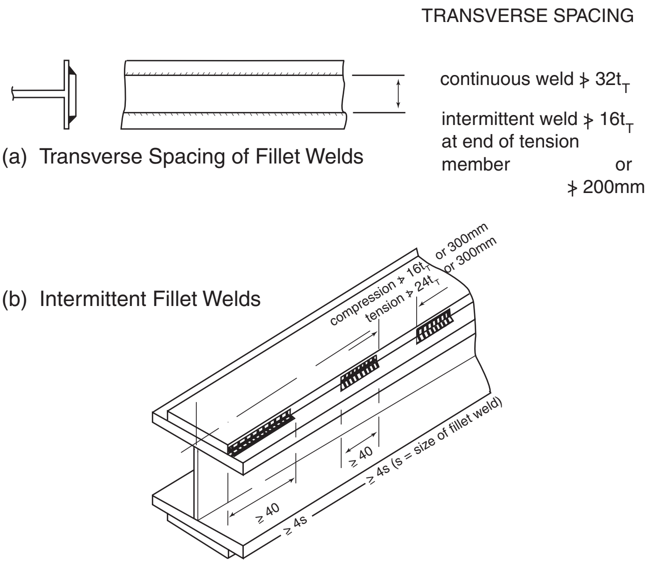

Figure A3.3.3 Provisions for Fillet Welds in Accordance with AS 4100 and AS 3990

A3.3.5 Minimum Size of Fillet Welds

The minimum sizes of fillet welds given in Table 3.3.5 of Part 1 could all be made as single run welds. It is recommended that the provisions of Table 3.3.5 of Part 1 also apply to the root run of multi-run welds even though Part 1 is not explicit in this regard.

The provisions of this clause are intended to ensure sufficient heat input is provided in order to reduce the possibility of cracking occurring in either the heat-affected zone or in the fillet weld itself, especially in restrained joints.

Whilst AS 4100 Table 9.7.3.2 and NZS 3404.1 Table 9.7.3.2 specifies minimum fillet weld sizes, AS 3990 does not require any minimum size of fillet weld. The Australian Bridge Design Code (Reference 1) now has minimum sizes identical to those given in Table 3.3.5, but other codes may not hence the note to Table 3.3.5. In all cases, it remains the role of the designer (and not the fabricator) to specify actual weld sizes required.

The reference in clause 3.3.5 to clause 5.3 is incorrect – it should be to clause 5.2.3.

A3.3.6 Maximum Size of Fillet Welds along Edges

The figures accompanying clause 3.3.6 are self-explanatory. Note that in case (b), the design throat thickness must be based on the size S which is less than t, while for cases (a) and (c) size S equals thickness t. The reason for the difference in case (b) is that, if top edge melting occurs, it is difficult to determine the true size of the fillet weld.

The AS 4100 and the Australian Bridge Design Code (Reference 1) requirements are the same as clause 3.3.6 but AS 3990 contains no similar provisions.

A3.4 Compound Welds

As noted in clause 3.4 of Part 1, a compound weld is simply a butt welded T-joint with a fillet weld superimposed. When qualifying weld procedures for such welds, it should be based on the corresponding butt weld (or incomplete penetration weld as the case may be) procedure with a fillet weld then superimposed.

A3.6 Plug Welds

Part 1 includes detailed provisions for plug welds which follow the requirements of AWS D1.1 section 2.3.5. The minimum diameter of hole is 8mm greater than the plate thickness. The maximum diameter equals the minimum diameter plus 3mm or 2.25 times plate thickness which ever is greater. The minimum centre-to-centre spacing of plug welds is 4 times the hole diameter. Depth of filling is full plate thickness up to 16mm and half plate thickness but not less than 16mm thereafter.

A3.7 Slot Welds

Slot widths follow the rules described above for plug welds. The length shall not exceed 10 times the thickness of the plate.

Note: *AS/NZS 1554.1 allows complete or partial filling of plug and slot holes depending on plate thickness as well as a fillet weld only around the perimeter of the hole in a plug weld. AS 4100 allows fillet welds or complete filling for both plug and slot welds.*

A3.8 Welds for the Purpose of Combining Rolled Steel Sections

This clause only deals with instances of very low or non-calculable stress, for which only a nominal incomplete penetration butt weld is required. The design engineer should specify the size of weld to be deposited. All the other relevant clauses of Part 1 naturally apply in such cases. Where such welds are subject to significant levels of shear force or bending moment, the designer must determine the size of weld required by conventional procedures.

A03.9 Provisions Not Included In Either AS/NZS 1554.1, or the Design Standards

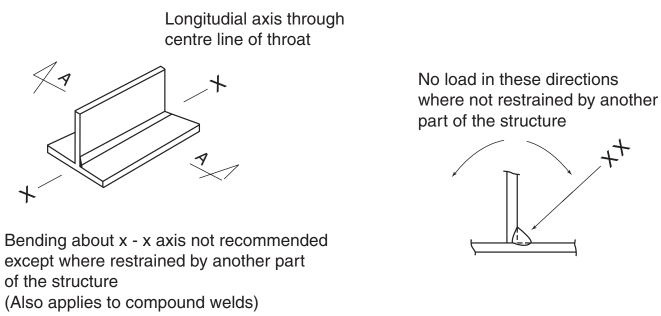

Figure A3.9.1 Single Fillet Weld Subject to Bending

A number of provisions of some importance are not at present included in either AS 3990, NZS 3404 or AS/NZS 1554. They rightly belong in the design Standards and among such provisions are the following.

(i) A single fillet weld should not generally be used where the fillet weld is to be subjected to bending about the longitudinal axis of the weld (Figure A3.9.1).

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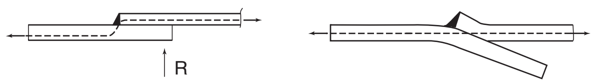

Figure A3.9.2 Single Fillet Welded Lap Joints

(ii) Single fillet welded lap joints subject to tension tend to open up and apply a tearing action to the root of the fillet weld, unless restrained by a reaction force R (Figure A3.9.2).

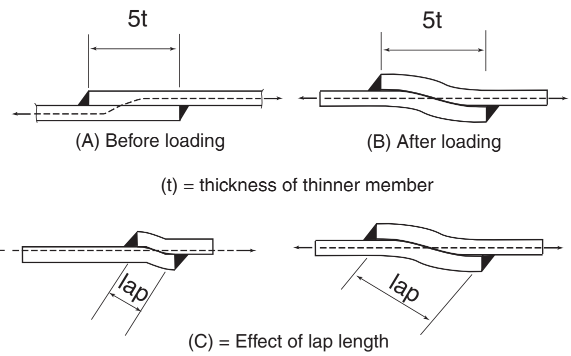

Figure A3.9.3 Examples of Lap Joints

(iii) A minimum width of lap in a lap joint is specified as five times the thickness of the thinner part but not less than 25mm in both AWS D1.1 (clause 2.8.1.2) and the Australian Bridge Design Code (Reference 1). Fillet welding is required along the edges of both lapped parts (Figure A3.9.3). The longer the length of the lap, the less the amount of flexing which occurs when the lap joint is subjected to a tensile force.

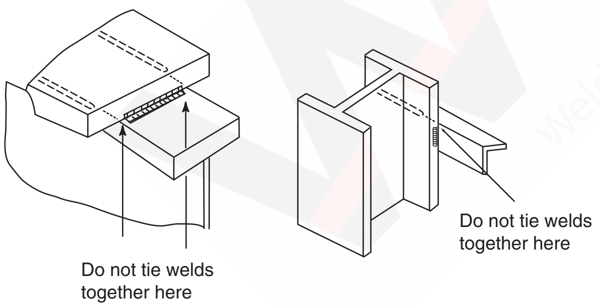

Figure A3.9.4 Fillet Welds on Opposite Sides of a Common Plane of Contact

Note: *AS 4100 Supplement 1, Steel Structures Commentary in its clause C9.7.3.10 (Figure C9.7.3.10(3)) does comment on lap joints, but AS 4100 and NZS 3404.2: 1997 do not.*

(iv) It is recommended that the design engineer or detailer specify that fillet welds be interrupted at corners where the fillet welds are deposited on opposite sides of a common plane of contact (see Figure A3.9.4). Otherwise, a potential point of weld cracking is created - this is particularly important in a cover plated beam subject to fatigue. The AWS commentary in clause C2.8.3.5 (part of AWS D1.1) provides the following comments on the types of joints shown in Figure A3.9.4:-

"An attempt to tie two fillet welds deposited on opposite sides of a common plane of contact between two parts could result in notches or masking of poor fit up".

(v) Where corrosion protection requires seal welds, small size fillet welds may be used around the corners. The use of the minimum sizes in Table 3.3.5 of Part 1 is suggested.

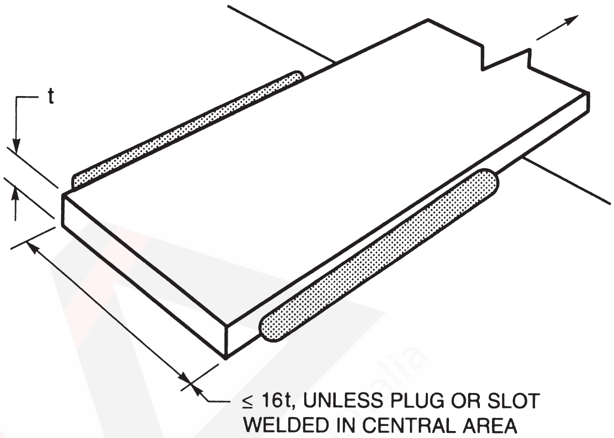

Figure A3.9.5 Fillet Welds in End Connections

(vi) AWS D1.1 (clause 2.8.2) recommends that because of shear lag, "If longitudinal fillet welds are used alone in lap joints of end connections of flat bar or plate members, the length of each fillet weld shall be no less than the perpendicular distance between them. The transverse spacing of longitudinal fillet welds used in end connections shall not exceed 16 times the thickness of the thinner connected part unless suitable provision is made (as by intermediate plug or slot welds) to prevent buckling or separation of the parts." This is illustrated in Figure A3.9.5.

A4 Qualification of Procedures and Personnel

A4.1 Qualification of Welding Procedure

The qualification of a welding procedure is divided into four parts:-

(i) qualification of the joint preparation;
(ii) qualification of the materials;
(iii) qualification of the consumables; and,
(iv) qualification of the welding parameters.

In general, procedure qualification should be carried out prior to the commencement of fabrication, but may, under certain circumstances, be done by inspection of the first unit produced. All welding procedures must be fully documented even if they are prequalified. Appendix C of Part 1 shows example pro forma documents suitable for use as either a Procedure Qualification Record or Welding Procedure Specification as detailed below.

The welding procedure will have all essential details on joint preparation, consumables and actual welding parameters (amps, volts, speed, preheat, etc) used. Records referring to the welding parameters used in the procedure test and results of the tests carried out are referred to as a welding procedure qualification record (WPQR or PQR). It is required that records of all testing carried out be preserved, since it is intended that welding procedures once qualified will be transferable to other projects and will, therefore, come to constitute a valuable part of a fabricator's assets.

From this PQR, the Weld Procedure Specification or Weld Procedure Sheet (WPS) is drawn up using the parameters used to qualify the PQR and adding the tolerances allowed under the essential variable requirements (section 4.11 of Part 1). A copy of this WPS must then given to the welder so that the procedure can be reproduced on the job and thus predictable weld properties and quality achieved.

This part of the Standard is often misunderstood. Adherence to pre-qualified preparations and consumables alone only qualifies a procedure in the case of GP category welds. In all other cases at least a macro test is required, plus other tests as specified in Table 4.7.1.

In the 1995 edition of the Standard, a clause was inserted to allow a representative of the principal to inspect and approve welding procedures (in previous editions this was only listed as an item for discussion under "Checklist of matters for discussion" in the Appendices). In the event that the principal wishes to approve all procedures, the fabricator is not absolved of his responsibility to ensure that the procedure is correctly qualified, documented and followed during fabrication. The Standard also requires the approving representative of the principal to have appropriate qualifications and experience so that the principal can be assured that the requirements of the Standard are being met by the fabricator.

New Zealand users should note that NZS 3404.1 Clause 1.6.3 note 4 requires the welding procedure sheets to be approved by a representative of the Principal (various options are given) prior to fabrication commencing. The reason for this requirement relates to the New Zealand experience that the great majority of welding related problems in structural steelwork are a result of inappropriate procedure usage. Independent approval of the WPSs offers an effective means of ensuring that the welding procedures are appropriate for the job. As stated above, the fabricator is still responsible to correctly produce these WPSs and ensure compliance with the requirements of Part 1.

Once the procedure is documented and qualified by testing (if required), a copy of the welding procedure sheet must be made available for the welder's use during fabrication. If the welder is not seen to be following the procedure, the fabricator can not assure the principal or inspection authority that the welding procedure has been followed. In such cases, condition (a) of clause 1.6 will not have been met and extra NDE may be required to verify that the structure has been satisfactorily constructed.

Note: *Specific guidance on the writing and development of welding procedures is available in WTIA Technical Note 19 and includes examples of PQR and WPS documents.*

A4.1.2 Butt Welds

Requirements for pre-qualification of butt welds were substantially modified in the 2000 edition of Part 1, with further minor changes instituted in the 2004 edition. The changes are self-explanatory. The purpose of the changes was to simplify and extend pre-qualification requirements without requiring further qualification tests of the fabricator. The changes allow a procedure qualified in one position to be used in another position within the limits of essential variables (clause 4.11) and Tables E1, E2 and E4 in all cases other than a change in direction of welding for vertical welds. The rationale behind this provision is that weld metal properties will not change with weld position as welding conditions and technique remain substantially unchanged within the limits of essential variables.

It should be noted though that procedures so developed may not be practical or economical in alternative positions e.g. a high heat input weld designed for welding in the flat position would most likely prove uncontrollable in the overhead position, and similarly a weld qualified in the overhead position may prove uneconomical to use in the flat position.

A4.1.3 Fillet Welds

Similar modifications were made to requirements qualification for fillet welds in the 2000 edition of Part 1. In this case qualification limits apply based on weld size with separate qualification required for single run and multi-run fillet welds. These changes reflect similar trends in pressure application standards and international welding standards.

A4.1.4 Qualification of Multiple Welding Positions

Clause 4.1.4 was inserted in the 2000 edition of Part 1 to provide fabricators with a simple method to qualify a weld procedure in multiple welding positions outside of those permitted by clauses 4.1.2 and 4.1.3.

A4.2 Method of Qualification of Welding Procedure

The clause lists the five methods by which a procedure may be qualified:-

(a) **Prequalified Procedure**
Where clause 4.7 does not require a macro test, adherence to prequalified consumables and preparations is sufficient. NB. This only applies to GP category welds (the parameters used in welding must still be documented).

(b) **Documentary Evidence**
A well documented procedure will include not only a weld procedure sheet, but also complete records of procedure qualification, any testing carried out, together with preserved macro specimens, sketches of macro specimens or photographs of macro specimens. In those cases where a fully documented

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procedure exists, the principal or his representative should only demand separate qualification where this is specified in the tender document. Additionally through this clause and application note, the fabricator is advised that procedures qualified to other National Standards such as AS 3992, AWS D1.1, ASME IX etc automatically meet the requirements of AS/NZS 1554.1 without further qualification testing. Whilst the methods of achieving qualification may vary from those of AS/NZS 1554.1, the end result of a satisfactory weld procedure will not. The fabricator however, must retain evidence of qualification as laid out in the original application Standard and weld within the restrictions of the essential variables in AS/NZS 1554.1 (e.g. Tables 4.11(A) and 4.11(C)).

Note: *The editors are aware of situations where testing laboratories have erroneously supplied the fabricator with a certificate or letter of conformance to AS/NZS 1554.1 without the required photograph or sketch of the macro test (where the test piece is not being retained by the fabricator). In such cases, the fabricator should submit a copy of this certificate or letter together with copies of fabrication NDE records for that procedure (to verify satisfactory use of the procedure) to the principal for consideration and concession under this clause. Similarly, this recommendation also applies where the testing laboratory has qualified the procedure through ultrasonic testing of the procedure test plate in lieu of the required macro test (the ultrasonic examination will reveal much more than a macro test).*

(c) **Qualification by Means of a Run-on and Run-off Piece**

It is recognised that there will be some variation in penetration, particularly in the case of run-on pieces. It is implicit in Part 1 that this variation will be acceptable for the type of construction envisaged under Part 1.

(d) **Preparation of a Special Test Piece**

Figure 4.7.2 of Part 1 shows an appropriate test piece for the qualification of a butt weld and fillet weld procedure. Care should be taken to ensure that weld access and restraint are simulated as closely as possible, particularly in the case of complex joints. The length of the test piece need only be sufficient to provide the test specimens require by Table 4.7.1 of Part 1. However, under certain circumstances, the geometry of the joint may be such that it will be impossible to obtain the tensile and bend specimens required and it may then be necessary to produce two test pieces; one simulating the weld geometry and the other to permit the required mechanical testing.

(e) **Destructive Testing of a Prototype**

In cases of multiple production, it will often be found that the qualification of welding procedures can more readily be achieved by the destructive testing of a prototype or a sample selected from a production series.

(f) **Welding Procedure Qualified by Another Fabricator**

See cause 4.4 and A4.4.

The fabricator should submit the proposed method (from (a) to (f) above) of welding procedure qualification, with the necessary supporting details, to the principal for approval. Methods (a) or (b) are preferred and should be used where possible.

Note: *If the parent material is to be prime painted or galvanised before welding, the welding procedure must be qualified with parent material having the same surface coated conditions. If the procedure cannot be qualified under these conditions, the paint or galvanising must be removed in the vicinity of the weld (clause 5.1.1). This requirement also applies where anti-spatter fluids and compounds are applied to the weld preparation prior to welding.*

A4.3 Prequalified Welding Procedures

When the fabricator elects to employ a prequalified joint preparation in accordance with clause 4.5, prequalified materials in accordance with clause 2.1 and prequalified consumables in accordance with clause 4.6 and does not deviate from other requirements of Part 1, particularly in regard to heat input and preheat, the welding procedure qualification will require, at most, the production of a macro specimen which will usually be obtainable from a run-on run-off piece.

This approach will not necessarily, however, lead to the most productive welding technique. The fabricator should give careful consideration to qualifying a more productive procedure initially in accordance with clause 4.2 (c), (d) or (e), and using this qualified procedure under clause 4.2 (b) in future contracts. Such qualified procedures may be employed with a minimum of further testing in future production under the provisions of clause 4.2 (b).

In general, the fabricator should adopt the prequalified joint preparations in Part 1 only in those cases where the quantity of welding to be done is insufficient to justify the costs of qualifying a more productive joint preparation and welding procedure.

Documentary evidence of a satisfactory macro includes a photograph or sketch of the test piece. This evidence should also clearly designate the number of weld runs, their sequence and location, and relevant dimensions such as weld leg length, throat thickness etc (this may be easily achieved by ensuring that photo or sketch is scaled to known dimensions).

The requirements for pre-qualification of materials was added to the 2004 edition of Part 1 following requests for guidance from fabricators for the welding of materials not listed in clause 2.1 given the broad application that Part 1 finds throughout the fabrication and construction industry.

A4.4 Portability of Qualified Welding Procedures

The 2000 edition of Part 1 introduced the concept of portability of welding procedures. Whilst permitted within AS 3992 under controlled circumstances, the ability for one fabricator to use procedures qualified by another fabricator within the structural steel industry under similar controlled circumstances has considerable benefits for all parties, particularly in large project based fabrication work where the main contractor may wish qualify all weld procedures and then pass these procedures onto their sub-contractor fabricators. Whilst the provisions in this clause are self explanatory it should be noted that procedures used by the second fabricator must remain traceable back to their source procedure qualification records otherwise re-qualification is required. At all times, each fabricator remains responsible for the quality and control of their own work.

A4.5 Prequalified Joint Preparations

The joint preparations given in clause 4.5 have been chosen such that they will be capable of producing satisfactory joints under even comparatively poor conditions of workmanship. They do not represent the upper limit of what individual processes can readily achieve. Substantial savings in terms of productivity are achievable under properly controlled fabricating conditions, particularly in terms of angles of preparations, root gaps and root faces. A fabricator should, therefore, endeavour to establish the most economic production method with regard to the equipment available and the experience of the workforce (see also A5.2.2).

Fabricators should take care when back-gouging all joint preparations and weldments, as poor control of the gouge shape, particularly in the root region, is known to be the cause of many subsequent welding defects. The back gouge must have a root radius suitable for the welding process being employed and should generally follow the dimensions provided for the prequalified single U preparations shown in Table E2. On thinner gauge plates, some fabricators are known to follow Pinky's rule in this respect i.e. *"… if a little finger cannot be easily inserted into a cool backgouged preparation by the welder, penetration and access problems will give rise to weld defects …"*. Care must be taken to avoid deep narrow gouges unless narrow gap welding techniques and equipment are to be employed. In addition, if carbon arc gouging is used, the gouge must be dressed to a depth of at least 0.25mm prior to welding i.e. to remove carbon pickup. When grinding, take care to avoid smearing the metal over the top of cracks, gaps and other discontinuities (magnetic particle examination is often specified after back gouging to detect such problems).

Users of GMA welding with CO_2 shielding gas at high current levels should note that, technically, this consumable/shielding gas combination will never enter the true 'spray mode' of metal transfer. Whilst not specifically mentioned in Part 1, users should treat the combination at high current levels (as defined in note 5 of Tables E1 and E2) as 'pseudo spray mode' and thus utilise the prequalified GMAW spray mode joint preparations in such circumstances.

Table E4 caters specifically for the structural steel hollow sections made to Standards such as AS 1163 and AS 1450. It is the only place in Part 1 where 'prequalified' ungouged full penetration welds are allowed where a backing bar is not used. As this table is only called up in clause 4.5.5, it is clearly not intended to apply to the welding of other forms of structural steels.

The requirements for procedure qualification of fillet welds on plate and pipe presented in Clause 4.1.3 of the 2000 and 2004 editions are further presented in Table 4.5.4. Unlike previous editions of Part 1 where the qualification of weld fillet size was governed by the material thickness, the single run maximum fillet size used in qualification now covers the test size and smaller and for multi-run the minimum size used in qualification covers the test size and larger.

Clause 4.5.5 was modified in the 2004 edition to cater for the welding of both equal width and unequal-width rectangular hollow sections following the completion of research on the structural requirements of these joints (Reference 7). An important outcome of this work was the fact that wherever possible, welds joints on rectangular hollow sections should not be started or stopped at corners and comments to this effect have been included this section. Similarly, the detrimental affects of the poor practice of welders using fill bars and other pieces of metal to bridge gaps in the welded joint was highlighted with the correct use of backing bars to bridge wide gaps confirmed to be structurally sound.

As a point of clarification, fabricators should note that where a joint type is considered "prequalified" over a wide range of thickness, the restrictions of Table 4.11.1(A) item (o) still apply to the procedure as tested. For example, if a 12mm plate is butt welded using joint type B-C2b, it is qualified for use over the thickness range 9mm to 18mm, not the full range implied in Table E1. Welds in thicknesses outside this range must be requalified.

Note that both Tables E1 and E4 make reference to a backing strip with the notation M or MR. These terms are defined in AS 1101.3 clause 4.6 and for convenience are repeated here:

- M = Material as specified
- MR = Same as M but removed after welding

A4.6 Qualification of Welding Consumables

Welding consumables should only be used within welding positions for which they are considered suitable and all welding parameters must fall within the limits specified by the manufacturer so as to maintain compliance with the consumable's classification. Use outside of the manufacturer's recommended limits and welding positions invalidates its classification and thus the consumable will need to be qualified by testing under the new conditions

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as described in clause 4.6.2 of Part 1. Parameters to which this comment applies include but are not limited to the amperage range, the wire/shielding gas combination and the wire/flux combination etc.

This also means that the consumables must not be used at service temperatures below their temperature grading as specified by the manufacturer in the consumable classification without further weld metal impact testing at or below the appropriate design service temperature (refer also to Appendix B of Part 1).

A4.6.1 Prequalified Welding Consumables

Pre-qualification of welding consumables is based on the selection of consumables that will give the as-deposited weld metal mechanical properties equivalent to those of the parent material when using any welding procedures meeting the requirements of Part 1. Mechanical properties considered are: tensile strength, yield strength, ductility, hardness and notch toughness. In addition, resistance to atmospheric corrosion and colour matching are considered for consumable pre-qualification of the welding of weather resistant steels to AS/NZS 3678 and AS/NZS 3679 (Tables 4.6.1(C) and clause 4.6.1.2 of AS/NZS 1554.1).

It is important to note that consumables are prequalified only for the nominated welding process, e.g. a FCAW consumable is NOT prequalified for an electroslag procedure.

Table 4.6.1(B) of Part 1 groups the Australian steels covered by Part 1 into types 1 to 8 depending upon their mechanical and impact properties. Table 4.6.1.(A) lists the welding consumables classifications that are to be used for each steel type number in order to be prequalified. Ship classification societies approval gradings are included in this Table to cover welding consumables for which an Australian Standard is not available. When these Standards become available, the appropriate welding consumables classification for the steel type number being used will satisfy the pre-qualification requirements for the welding consumable. A T grading (two run) covers large single run procedures such as a butt weld, welded one run each side. The restrictions on heat input given in clause 4.6.1.1 (d) and (g) are to ensure that weld metal impact properties do not fall below the minimum specified for the parent material.

No limitations are placed on heat input for:-

(a) consumables with the appropriate T or TM grading;

or

(b) if the welding procedure is qualified by testing (clause 4.6.2);

or

(c) if the fabricator can produce documented data showing satisfactory prior use of the consumable and procedure.

The last exemption is the basis of the philosophy of Part 1 which encourages the documentation of procedures and the acceptance of this documentation as sufficient to give prequalified approval of the procedure on other work. The aim of Part 1 is to minimise the need for procedure and consumables qualification test pieces on any work welded to the requirement of Part 1.

The grouping of steels in Table 4.6.1(B) of Part 1 recognises the following:-

(a) Steel grades with no specified impact properties (types 1,4) may be welded with consumables that produce weld metal which has no specified impact properties;

(b) Steel castings to AS 2074 were subject to Izod impact test provisions in the 1982 edition however these requirements were updated to Charpy impact values in the 2003 edition. The new impact requirements are not directly equitable to any of the impact tested wrought steel grades, however, it is considered that non-impact tested wrought steel will have at least equivalent toughness properties. Based on this assessment, the steel castings have continued to be grouped on a similar basis to the non-impact tested wrought steel grades;

(c) AS 1163 steel sections have been treated as if there will be no reduction in heat affected zone mechanical properties. This will be largely true of most sections except the smaller square and rectangular sections, particularly at corners where high levels of cold strain may be involved. For such sections, separate qualification of the welding procedure should be considered or pertinent data requested from the section manufacturer.

The designer and fabricator should take care when specifying steel types and welding consumables due to the brittle fracture requirements of both. The designer should always advise the fabricator of the design temperature (see Appendix B) so that a welding consumable with appropriate impact resistance can be selected irrespective of the steel type and grouping. The reason for this is that Table B1 allows some steels to be used at temperatures below their impact test temperature thus under such circumstances, welding consumables will be required to at least have appropriate impact resistance at the same service temperature.

Note: *1) Where two steels of different impact test requirements are being joined, the heat input restrictions of the least critical steel apply (i.e. the non-tested steel or the highest temperature tested steel) e.g. if an L15 type steel is being welded to an L0 type steel, the heat input restrictions of the L0 steel apply to the joint, not the L15 restrictions. The reason for this is that the notch toughness of the joint is limited by the lesser requirements of the L0 steel.*

2) Welding consumables that have AWS classifications are not automatically deemed as prequalified to the Australian Standards unless such consumables have been classified by the Ship-classification societies as listed in Table 4.6.1(A).

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3) New Zealand seismic design requirements call for welding consumables with specified impact properties (see NZS 3404.1 Clause 2.6.4.5.2).

A4.6.2 Qualification of Welding Consumables by Testing

This section is basically self explanatory, however, users of AS 1163 cold formed sections in particular should be aware that some grades may not meet the minimum tensile properties given in Table 4.6.2 (this occurs because the steel type numbers of Table 4.6.1(B) are based on minimum yield strengths, not minimum tensile strengths). For these and other similar cases, the note will apply and provided that the tensile test specimen breaks outside the weld zone (in either the parent material or the weld heat affected zone) and meets the minimum tensile strength for the parent material, the tensile test result is deemed to comply i.e. the note applies to all steel types, not just steel types 1 to 3 as indicated in previous editions of the Standard and corrected by Amendment No1 in 1998.

A4.7 Qualification of Welding Procedure by Testing

A4.7.1 Method of Qualification

The testing required for SP category welds is intended primarily to:

(a) ensure adequate penetration and freedom from defects when using prequalified preparations and consumables;

(b) ensure adequate weld metal strength and ductility when using non-prequalified consumables;

(c) ensure freedom from excessive HAZ hardness when the heat input/preheat requirements of Part 1 are not observed.

(d) affirm that the notch toughness of the weld metal from non-prequalified consumables when fabricating notch toughness-tested plate is satisfactory.

With the substantial changes to clause 4.1.3 in the 2000 edition, requirements for validating weld procedures for prequalified category SP fillet welds were further enhanced with the addition of macro tests for such welds within Table 4.7.1. The table was further amended in the 2004 edition to clarify the qualification requirements specified in clause 4.7 and Table 4.7.1, particularly for situations where the butt weld test assembly and associated tests would be required to qualify fillet weld tests.

For GP category welds, no confirmation of weld metal strength or ductility is required. The level of permissible imperfections accepted for this weld category has made it possible to eliminate the need for macro tests when employing prequalified consumables and preparations. However, although Part 1 does not require it, a fabricator may elect to carry out these tests for internal quality control purposes.

A guidance note was also added to clause 4.7.1 in the 2000 edition to provide assistance to fabricators on the requirements for qualifying non-prequalified steels. Whilst clause 2.1 was amended to enhance these requirements in the 2004 edition, this guidance note was retained in the 2004 edition to cater for situations not effectively covered by clause 2.1 requirements.

A4.7.2 Preparation of Special Test Piece

Where the joint geometry is such that it is impossible to extract tensile and bend test specimens, and where these are required by Table 4.7.1 of Part 1, it is necessary to prepare a special test piece in accordance with Figure 4.7.2 of Part 1.

A4.7.3 Dimensions of Test Pieces

The test piece need only be sufficiently long to obtain test specimens required for the qualification tests of Table 4.7.1 of Part 1. However, where the joint restraint is of unusual severity, it may be necessary to employ a longer test piece or to employ strong backs to adequately simulate the restraint. Although not covered by Part 1, the test piece may also be employed to verify any non-destructive testing procedures required for the actual joint.

A4.7.4 Macro Test

The macro test is intended to show whether a weld exhibits satisfactory root, side wall, and interrun fusion and to show freedom from levels of weld imperfections above those permissible. The individual weld beads should be measured to determine that they exhibit the width-to-depth ratio required by clause 5.6 of Part 1. Ratios in excess of the requirements of clause 5.6 of Part 1 are susceptible to hot cracking. Exposed imperfections should not exceed a cross-sectional area loss of 5% for SP category welds, and 10% for GP category welds, nor should the sizes of individual imperfections exceed those specified in Table 6.2.2 of Part 1.

Given that the macro test is taken transverse to the weld, internal imperfections revealed by the test piece must be assumed to run the full length of the weld and assessed accordingly to Table 6.2.2 unless it can be proved otherwise (e.g. radiographic or ultrasonic testing of the remainder of the test plate, further macro tests etc). Refer also to clause 6.2.4 of Part 1.

Note that if the test piece is not being retained by the fabricator, AS 2205.5.1 requires the testing laboratory (or fabricator) to include a photograph or sketch of the macro in the report (scanning a well prepared macro test piece with a flat bed scanner or photocopying it will also produce a reasonable result and meet this requirement). Similarly, as noted in section A4.3 of this commentary, it is important that photographs or sketch be accurately scaled so that the required measurements may be made from the image as required to assess compliance with Part 1.

A4.7.5 Transverse Butt Tensile Test

The purpose of this test (performed in accordance with AS 2205.2.1) is to show that non-prequalified weld metal has sufficient tensile strength. The minimum tensile

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strength of the test specimen must be at least equal to the value of the tensile strength specified for the appropriate steel types in Table 4.6.2. of Part 1.

A4.7.6 Bend Test

The bend test (to AS 2205.3.1) is intended as an approximate measure of weld joint ductility. The radius of bend is dependent on the plate tensile strength and thickness (see Table 4.7.6 of Part 1). Higher strength materials often exhibit lower ductility.

A4.7.7 Charpy Impact Test

Charpy impact tests (to AS 2205.7.1) are only required where non-prequalified weld metal is employed to weld notch toughness tested plate. It should be noted that in the case of SAW, pre-qualification of consumables to AS 1858 extends only to a maximum heat input of 5kJ mm for L0 steel grades. However, welding consumables for SAW with ship classification societies approved for T or TM grades are not subject to these heat input restrictions (see clause 4.6.1.1 (e)). The Charpy test is intended to demonstrate that the weld metal has sufficient notch ductility and that it will not reduce the overall brittle fracture performance of the structure under the loading and weld defect levels and service temperature envisaged in Part 1 (note also Appendix B of Part 1).

Under conditions involving relatively high heat input welding procedure (>3.5kJ/mm), it may be prudent to supplement the weld metal Charpy testing with similar tests in the plate HAZ. The advice of the steel supplier on the levels of heat input where this might become desirable should be obtained.

A4.7.8 Hardness Comparison Test for Parent Metal and Weld Metal

This test is intended to ensure that the strength of the weld metal does not greatly exceed the strength of the parent material, in order that, when plastic deformation occurs, it is not concentrated in the parent metal heat affect zone (HAZ). The 1980 edition of Part 1 limited the hardness of weld metal to not more than 60HV10 greater than the parent material. This limit proved impracticable for some welding processes and was increased to 100HV10 in the 1985 and subsequent editions. The hardness comparison test is only required for non-prequalified weld metal and SP category welds.

A4.7.9 Hardness Test for Weld-heat-affected Zones

This test (to AS 2205.6.1) is intended to be used where the preheat/heat input requirements of Part 1 are not followed. The value of 350HV10 has been chosen so that with materials of construction complying with clause 2.1 of Part 1 there should be very little danger of HAZ cracking. It should be borne in mind that the value of 350HV10 is conservative and many of the materials currently used are capable of sustaining a higher value without cracking. If values higher than 350HV10 are obtained, then the procedure under examination may be employed, provided that the fabricator can demonstrate to the satisfaction of the principal that the weld is suitable for the intended purpose. This is the reason for the reference to Appendix B in clause 4.7.9 of Part 1. In such circumstances, an increased level of non-destructive examination may be justified.

A4.8 Extension of Qualification

Procedure qualifications for SP category welds may be used without further testing for GP category welds and hence there are advantages in qualifying all welding procedures for SP category welds.

Procedure qualification obtained for one steel grade may be used without further qualification testing for:-

(a) steels of a lower yield strength or where the specified minimum yield strength of the other steel does not exceed that used in the qualified procedure by more than 51MPa; and

(a) the steel type number (Table 4.6.1(B)) has not increased; and

(c) steels with lesser notch toughness requirements e.g. a procedure on a steel with notch toughness requirements at -15°C may be used for a steel with notch toughness requirements at 0°C; and

(d) steels where the Weldability Group Number is not higher; and

(e) weather resistant steels where patina formation is not critical.

Item (a) was modified and item (b) inserted into the 2000 edition of Part 1 in recognition of the introduction of steel types within AS/NZS 3678 and AS/NZS 3679 with minor increases in strength without significant changes to steel chemistry or weldability. This provision permits, for example, weld procedures qualified on AS/NZS 3678 grade 250 to be used without modification on similar AS/NZS 3678 grade 300 steels but does not allow weld procedures qualified on AS/NZS 3678 grade 300 to be used without modification AS/NZS 3678 grade 350 steels.

A4.9 Combination of Processes

The use of different processes for each side of a welded joint is permissible provided that the joint preparations are those specified for the applicable processes.

A4.10 Record of Tests

It is of the utmost importance that a full record be maintained by the fabricator of all welding procedure qualification tests undertaken (including a record of actual welding parameters used to produce the test plate), together with macro specimens or photographs (or sketches or digital images) of macro specimens pertaining to the procedure. These records form the basis of the PQR which is the accepted method of pre-qualification of the procedure (WPS) for future welding carried out to Part 1 (see clause 4.2(b)).

A4.11 Re-qualification of Welding Procedures

A04.11.1 Changes in Essential Variables Requiring Re-qualification of Welding Procedure

A comparatively wide variation in welding parameters from those specified (i.e. qualified) on the procedure documents is permitted without re-qualification. The fabricator would be well advised to employ much closer tolerances than those listed in Table 4.11(A) of Part 1 for internal quality control purposes. A considerable reduction in the amount of qualification testing required is possible if the tests are carried out on materials of appropriate thickness and advantage is taken of provisions of item (o) of Table 4.11(A) which permits a thickness variation from the test piece thickness of -25% +50% without re-qualification. By judicious selection of the test piece thickness, the fabricator can qualify a procedure for a wide range of operations.

The following items in Table 4.11(A) are worthy of special comments:-

(b) suggests that the amount of qualification testing can be reduced by qualifying all procedures using the highest weld metal strength grade appropriate to the steel type (Table 4.6.1(B)), since re-qualification for lower weld metal strength grades is not required. Additionally, it should be noted that *'A change in consumable classification … '* refers to the base level classification of the consumable such as E4818 in the case of say an E4818-1 type consumable, however, the fabricator needs to be mindful of other requirements of Part 1 particularly the need to ensure compliance with clause 4.6.1.1 and its brittle fracture provisions i.e. the impact test temperature for the welding consumable shall not be warmer than the design service temperature.

(d) applies where a consumable type is changed within a process e.g. changing from a rutile FCAW wire to a metal cored FCAW wire, or from a gas shielded FCAW wire to a self shielded FCAW wire, or from a E4818 to a E4828 consumable etc. The additional requirements that apply when a consumable with a higher hydrogen classification than that originally qualified was added in the 2000 edition of Part 1 to minimise the risk of hydrogen cracking of weld metal (note also item (p) below). Fabricators using anti-spatter fluids should also note that the use of such fluids within the weld joint may void the hydrogen control status of the consumable. It has been shown that such inappropriate use of anti-spatter fluids with the normally very low hydrogen GMAW process (H_5 status) can raise its weld metal hydrogen level to H_{10} or H_{15} status thus raising the risk of hydrogen cracking in such circumstances (Reference 8).

(e) applies to changes in gases or gas mixtures but not to similar gases or gas mixtures from different gas suppliers. Prior to the 2004 edition of Part 1, the nominal composition of the gas was taken as the reference point for this limitation, however the 2004 edition of Part 1 referred to a change in gas classification in AS 4882 and thus given the latitude in composition and classification tolerances provided for in AS 4882, it is now permissible for fabricators to substitute a gas of one composition with another similar (non-identical) mix. For example, a procedure originally qualified using an Argon based 23% CO_2 mix can now be welded with an Argon based 25% CO_2 mix (i.e. within the 10% relative tolerance allowed in AS 4882) without further qualification.

(f) and (g) suggest that the fabricator should not rely on welding machine meters for measurement of welding current and voltage during qualification of welding procedures. It is recommended that calibrated separate meters (e.g. a 'tong' tester) be used for welding procedure qualification, and that these meters should be maintained specifically for procedure qualification purposes or for the calibration of machine meters. A welding procedure done using one welding machine need not be requalified for another equivalent machine, provided that the welding current and voltage are checked using the same meters. Note that in using these meters (and internal meters on the welding machine), the point of measurement must be as close as possible to the arc as the length of welding cables can have a significant affect on the validity of voltage reading and weld quality i.e. the volts measured may be higher than the actual voltage measured at the welding arc.

Note: *Whilst amp meters on welding machines can be reliably calibrated, it is often not practical to calibrate the volt meters on welding machines because of the large voltage losses that are known to occur in welding cables (refer to AS 1674.2).*

(j) is to avoid the situation where the loss of an effective gas shield may occur when the shielding gas flow rate reduces by 10% or more from the flow rate used for qualification of the welding procedure. Excessively high shielding gas flow rates cause turbulence and draw air into the arc region, and it is therefore required that the welding procedure be requalified if the flow rate increases by 25% or more over that used for the welding procedure qualification.

(k) applies only outside of the provisions of clauses 4.1.2 and 4.1.3. This clarification was omitted in error in the 2000 edition of Part 1 but was corrected in the 2004 edition.

(m) The intent is that a qualified procedure may be used without further testing on a steel of lower Group Number of similar thickness with a reduction in preheat but since preheat influences penetration a 20° limit is imposed. However the preheat requirements from clause 5.3.4 are paramount and (m) in Table 4.11(A) does not permit the use of preheat 20°C below this required level. Note that as actual plate thicknesses increase even within the limits provided by item (o) below, preheat requirements must be reassessed in accordance with clause 5.3.4.

(n) means a change from single-arc to multiple-arc, or vice-versa.

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(o) applies specifically to a variation in thickness from the actual test plate thickness. It should be noted that when this allowance is applied, preheat calculations must be checked as it may be necessary to increase the minimum preheat over that applied when qualifying the welding procedure. This item does NOT refer to a change in combined thickness (see clause 5.3.4 of Part 1).

When welding steels of different thicknesses together, the allowance given in the clause is calculated based on the thinner of the sections. From here, it must be applied with care. Provided that the ratio of thickness between the plates does not increase (i.e. the plate thicknesses are moved closer to the 1:1 ratio), this allowance can be applied. However, if it is necessary to increase the difference in thickness between the plates, the allowance must not be applied and each change or variation regarded as a minor change in essential variable and macro tested accordingly. The reason for this recommendation is that weld bead shape (particularly in the root region of the weld) changes very quickly as the difference in thickness between the plates increases and is known to cause problems with the weld bead depth-to-width ratio (clause 5.6 of Part 1), which can lead to centreline cracking in particular. Additionally, large differences in plate thickness are known to be associated with penetration problems (too much in the thinner steel and a lack of penetration or side wall fusion in the thicker).

(p) applies specifically to the semi-automatic and fully automatic welding processes indicated. The users attention is drawn to recent research (Reference 9) that indicates that when using short stickouts, seamed rutile flux cored wires may have difficulty maintaining compliance with their stated weld metal hydrogen classification. In such circumstances, guidance should be sought from the consumable manufacturer as to the range of stickouts and welding conditions that the weld metal hydrogen classification is maintained.

(q) the requirements of this item were clarified with the addition of a note to clause 4.11 in the 2004 edition of Part 1. The note is self explanatory.

Note: *Where ever Table 4.11(A) uses the word "specified", it should be interpreted to mean the value qualified in the procedure qualification tests and shown on the procedure qualification record.*

Minor changes in welding parameters which significantly affect only weld penetration but not weld metal properties are described in Table 4.11(C). With the provisions of clause 4.1.2 added into the 2000 edition of Part 1, item (d) of Table 4.11(C) was modified so that the change of preparation shape affecting penetration became the essential variable. It should be noted that whilst the J type preparation is not specifically included in the text, the J-shape should be regarded as a modified U-shape and thus is captured under item (e) of Table 4.11(C). A change in weld shape from U type to V type is permitted within the limits of item (i) of Table 4.11(A) without additional testing because the latter provides greater access within the joint preparation, however a change from V type to a bevel type preparation is regarded as a minor change in essential variable (item (e) of Table 4.11(C)).

A4.12 Qualification of Welding Personnel

The qualification requirements for welding personnel draw attention to the fabricator's responsibility for producing evidence of supervisor and welder qualification.

A4.12.1 Welding Supervisor

The Welding Supervisor's function is to ensure internal quality control during the welding and fabrication process. The Welding Supervisor would normally be an employee of the fabricator but in some cases may be contracted to the fabricator to perform such functions.

Although certification to AS 2214 (or the alternative formal qualifications listed in clause 4.12.1(a) to (d) of the 2004 edition of Part 1) is not mandatory for the Welding Supervisor, such certification does provide evidence of the technical knowledge of a Welding Supervisor for work particularly in the SP weld category and is the preferred option. Regardless of which other category of the clause ((e) to (h)) the welding supervisor qualifies under, evidence is still required of their technical knowledge. The 2004 edition of Part 1 clarified these minimum requirements by referencing AS 2214 which allows the Principal or Inspecting Authority to audit against the learning outcomes specified in AS 2214.

The Welding Technology Institute of Australia conducts examinations for its own certificate based on tests as required in AS 2214, as does the New Zealand Institute of Welding for its Welding Supervisor Certificate. A Supervisor with such certificates and those listed under items (a) to (d) must be automatically accepted under the terms of the clause, and fabricators are to be encouraged to employ such people, since this avoids the situation of one principal accepting a Welding Supervisor under (e), (f), (g) or (h) while another principal rejects the same Welding Supervisor.

A number of substantial changes were made to clause 4.12.1 in the 2004 edition of Part 1. In summary, these were:

- Changes made to the wording to the reflect changes within AS 1796 and AS 2214;
- All formal welding supervisor or higher qualifications (items (a) – (d)) were grouped together;
- Add reference to the International Institute of Welding specialist, technologist and engineer diplomas now recognised and awarded to suitably qualified people in Australia and New Zealand and over 30 other countries, and thus assisting to reduce a technical barrier to trade as required by the General Agreement for Tariffs and Trade (GATT) and Standards Australia policy;
- Set a minimum level of technical knowledge requirements for the remaining items (e) – (h) by referencing the learning outcomes provided in the 2004 edition of AS 2214.

Fabricators working with quality management systems complying with AS/NZS ISO 3834 and its parts should note that these documents refer to 'welding coordination' personnel. The minimum recommended technical knowledge requirements for welding coordination personnel is defined in ISO 14731. Welding coordinators may be required to perform a variety of tasks, one of which is welding supervision and should have sufficient technical knowledge and experience to competently undertake the task at hand. It is recommended that welding coordinators undertaking welding supervision tasks in accordance with AS/NZS 1554 and its parts should at least have a welding supervisor or specialist qualification unless more extensive technical knowledge is required in accordance with the contract in which case knowledge at the level of welding technologist or welding engineer may be required. Such requirements though remain a matter for resolution between the fabricator and Principal.

A4.12.2 Welders

This clause was substantially modified in the 2000 edition of Part 1 to clarify its intent with former sub-clauses that applied to all welders moved to paragraph status at the head of the clause. The requirements are self-explanatory.

Anyone who satisfactorily completes prescribed qualification tests (item (b)) or meets the requirements of the clause under item (a) may carry out the work for which they are qualified. Fabricators must recognise their responsibilities for training and evaluation of welders and ensure that their skills are maintained. The simplest and easiest method of verification of skill is to maintain appropriate NDE records (especially ultrasonic and radiographic test records) traceable back to the welder.

All welders must qualify for each weld procedure to be used on the job by means of a macro test, unless they can demonstrate successful prior experience with that procedure (e.g. through NDE records) or are working within the limitations of the qualification obtained under clause 4.12.2(a). Once qualified to weld specific procedures, welders are permitted to extend their qualifications depending on the original position qualified by the welder. Table 4.12.2, introduced in the 2000 edition, with origins in ISO 9606.1, provides extensive guidance to the fabricator over and above that available in previous editions of the Standard.

Whilst not specifically mentioned in clause 4.12(a), welders with valid qualifications under other national or international Standards are deemed to comply with this clause. In all cases, welders with these qualifications, and those specifically listed in this clause, are deemed to comply only whilst working within the limitations of their original qualification (note especially the limitations within AS 2980). Additionally, the fabricator must still ensure that the skills obtained during the original certification process have been maintained.

Further limitations on welder qualifications were inserted into clause 4.12.2 of the 2000 edition of Part 1 that requires welders to maintain their welding skills. The six month time limit specified is consistent with the requirements of AS/NZS 3992 and ISO 9606.1.

Welders who change employment are required to requalify, however, this provision is not applicable in cases where the welder has moved to a new employer as part of an out-sourcing, takeover or 'partnering' arrangement where the welder's qualification records remain available to the new employer. Similarly, welders contracted out by labour hire companies do not require re-qualification where the labour hire company (i.e. their employer) maintains the welder's qualification records and such records are made available to the contracting fabricator.

Note: *Where welders are required to weld through holes, with the aid of mirrors, low to the ground or in other restricted conditions, it is strongly recommended that the fabricator train and qualify such welders under conditions similar to those being encountered on the job as it is often very difficult even for experienced welders to produce quality welds in such circumstances.*

A5 Workmanship

A5.1 Preparation of Edges for Welding

A5.1.1 General

This clause requires that the weld preparation and adjacent areas should be free from material likely to adversely affect the properties of the weld, but it does not require grinding or other special preparation, nor does it prohibit the use of weld-through primers or anti-spatter fluids and compounds. It is necessary however, to qualify the weld procedure on surfaces and edge conditions similar to those to be used in production. If the procedure cannot be qualified under these conditions, the surface coating (including anti-spatter) must be removed in the vicinity of the weld.

Care should be taken when welding though surface coatings (including mill scale) as in certain circumstances including where welder access is restricted, lack of fusion and weld penetration problems can be encountered. Similarly, whilst the use of anti-spatter fluids is unlikely to cause weld penetration problems, it will rapidly elevate weld metal hydrogen levels leading to an increased risk of hydrogen cracking (Reference 8).

A5.1.2 Thermal Cutting

Thermally cut surfaces which are to be incorporated into a weld shall have a surface roughness no worse than that of Class 3 of WTIA Technical Note 5. Surfaces not to be incorporated into a weld are subject to requirements of AS 4100, NZS 3404 or AS 3990 which are, in any case, based on the requirements of Technical Note 5.

Adherence to the surface recommendations of WTIA Technical Note 5 is recommended.

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A5.2 Assembly

A5.2.1 General

In some instances (e.g. column splices) the alignment of the joint to be welded is specified in an application Standard such as AS 4100, NZS 3404 or AS 3990. However, many welded joints do not have an alignment requirement specified in an application Standard, in which case the drawings should state if any special requirements are necessary. Accordingly, the clause should be interpreted "as specified in the application Standard or on the drawings".

A5.2.2 Alignment of Butt Welded Joints

The tolerances in clause 5.2.2 and Table 5.2.2. of Part 1 are taken from AWS D1.1 (clause 5.22.4.1 and Figure 5.3). The prequalified joint preparations of Table E1, E2 and E4 in Appendix E may be varied by the amounts given in this Table. Judicious selection of limiting conditions can result in significant reductions in the volume of weld metal required for a given prequalified joint preparation.

It should be made clear that the prequalified preparations are exactly as shown in Table E1, E2 and E4 and the allowances in Table 5.2.2 are for workmanship purposes only. Some may try to claim the tolerance once for the qualification test and again for production. This is not intended.

The misalignment tolerance in clause 5.2.2 was amended in the 2004 edition of Part 1 due to practical difficulties in meeting the 10% misalignment tolerance limit. The change will allow the fabricator to exceed the 10% tolerance limit with the approval of the Principal, both parties having given consideration to the risks and implications to the design and safety of the structure in doing so (see also clause 1.8.3 of Part 1). Hazards that should be included in risk assessment deliberations should include the stress raising and stress concentration affects and the fatigue implications of the increased misalignment.

It will be noted also that adherence to the root gap and face values in Table E1 (and Table 5.2.2) is not required for back-gouged procedures.

The intention of the last paragraph of the clause is that the root gap of the prequalified preparation, already increased by the maximum position tolerance given in Table 5.2.2, may be still further increased up to a limit of twice the thickness of the thinner part, or 19 mm, whichever is the lesser. This arrangement does, however, require correction by welding to restore the prequalified maximum root gap. Buttering of one or both of the abutting faces is permitted for this purpose.

This concession had its origins in AWS D1.1 (clause 5.22.4.3) provisions and is intended to accommodate the practice, in building frames, of using a wide root gap to accommodate the closing weld and where weld shrinkage in other welds has caused a wide root gap. The rule applies to welds with and without backing bars although backing bars would normally be used when root gaps are wide. The upper limit is imposed to ensure that excessively wide welds (with associated distortion management problems) are not used.

A5.2.3 Alignment of Fillet Welds and Incomplete Penetration Butt Welds

This clause limits the gap between members to 5mm for materials less that 75mm in thickness and 8mm for thicker materials, in recognition of the fact that it will not always be possible to obtain complete surface contact with the materials employed for this class of construction.

Where gaps in excess of 1.5mm are used, it is necessary to increase the leg length of the fillet weld to compensate for the increased root gap, unless the fabricator can demonstrate through other methods (e.g. a macro test) that the required design throat thickness has been achieved.

A5.2.4 Separation of a Backing Material

The faying surface is the mating surface of a member which is in contact or in close proximity with another member to which it is to be joined.

A5.3 Preheating and Interrun Control

The requirements of this clause are derived from WTIA Technical Note 1, and are intended to ensure freedom from HAZ cracking under almost all fabrication circumstances. It must be remembered, however, that under conditions of extreme restraint, some HAZ cracking may still occur and it is anticipated that this will be detected by the procedure qualification and can be checked if necessary by the non-destructive testing requirements of Part 1.

Note that neither Part 1 nor Technical Note 1 address the issue of weld metal hydrogen cracking. Following considerable research however, WTIA Panel 2 published a guidance note for insertion within the Technical Note (see the text box below). If encountered, weld procedure modifications including the application of additional preheat beyond that predicted, and the use of very low hydrogen type consumables (rated at H5) etc. may be required. There is evidence that weld metal cracking is more likely to occur in restrained joints over 25mm thick and also in cases where higher heat input runs are used (i.e. larger weld bead sizes).

Further information on the mechanism and avoidance of hydrogen cracking can be found in reference 10. Fabricators should note in particular the time delay mechanism of hydrogen related cracking and therefore it is recommended that the timing of both destructive and non-destructive tests take this into consideration. In most cases, hydrogen related cracking will normally be detectable within 24 hours but it should be noted that such cracks, once initiated may continue to grow for several days (Reference 11).

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Historically the need for preheat during the welding of ferritic steels has been dictated by the susceptibility of the Heat Affected Zone (HAZ) to cold cracking. It was assumed that procedures that provided freedom from HAZ cold cracking also provided freedom from cold cracking in the weld metal. Consequently, current welding Standards and WTIA Technical Note 1 are based entirely on the avoidance of HAZ cracking and do not provide guidance for the avoidance of cold cracking in the weld metal. However, advances in the production of lower carbon equivalent steels have reduced the risk of cold cracking in the HAZ and in some instances weld metal cold cracking is more likely than HAZ cracking.

Moreover, it is becoming apparent that some measures that reduce the risk of HAZ cracking, such as high heat input, can increase the risk of weld metal cracking, especially when welding highly restrained thick section (greater than 20 mm) structures.

Whilst there is a considerable research effort underway investigating this problem, the prevention and control mechanisms for weld metal cracking are yet to be quantified.

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

Likewise, it is known that plate surface contaminants (see Chapter 7 of Technical Note 1) and remnant lubricants on wire from the manufacturing process decompose in the arc and raise the weld metal hydrogen levels, even when using “very low” hydrogen (H5) welding consumables.

Typically, weld metal cracking is transverse to the weld direction and can be subsurface or surface breaking. Detection using conventional radiographic and ultrasonic techniques is difficult and unreliable. To detect such cracks ultrasonically, it is necessary to remove the weld reinforcement to provide a flat surface for probe engagement and allow the ultrasonic beam to reflect from these imperfections laying transverse to the direction of welding.

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

The first step in calculating preheat is to calculate the Weldability Group Number. Traditionally this has been done simply by looking up a table of grades and then reading off its number. The 1995 edition of AS/NZS 1554.1 introduced an alternative method based upon knowledge of the steelmaker’s ladle or heat analysis published on the test certificate available with the steel plate when purchased. By calculating the Carbon Equivalent from the supplied analysis using the International Institute of Welding formula (clause 5.3.4(a)(ii) equation (1)), and adding an adjustment value to allow for possible statistical variations, the Weldability Group Number can be obtained by reference to Table 5.3.4(B).

This latter method was first adopted in the WTIA’s Technical Note 1 published in 1994 and was accepted after the review of many years of Australian steelmaking statistical data which showed a uniformity of analysis results. Adoption of this method of calculation, instead of the traditional method which is based on the maximum allowed specification, may allow the fabricator to use reduced preheat in some cases where material analysis may be at the lower end of the specification range.

The concept of combined thickness allows the user to apply a correction factor to preheat calculations when welding different joint thicknesses and configurations. It is calculated by adding together the actual plate thickness of all heat paths (i.e. cooling paths) within the steel pieces being joined. For example a simple butt weld has a combined thickness of $t_1 + t_2$ (see Figure 5.3.4(A) in Part 1) whereas a simple fillet weld would have a combined thickness of $t_1 + t_2 + t_3$. Refer to WTIA Technical Note 1 for further information.

An example showing how both preheat calculation methods work is set out on page 37. To simplify calculations, Table A5.3 shows the workings for the traditional calculation method for this example.

Using this example to compare the two methods of calculating preheat clearly demonstrates the dramatic saving that can be made in some circumstances where the ladle analysis of the steel is such that it places the steel in a lower weldability group than the traditional method. In this example, depending on factors such as restraint and ambient temperature, it may allow a reduction in preheat requirements from 70°C to 0°C i.e. the potential to eliminate the need to preheat – a very significant cost saving to industry.

In addition to the above methods of preheat calculation, the fabricator may decide to employ a lower level of heat input or preheat if it can be demonstrated by procedure testing, and to the satisfaction of the principal, that either HAZ hardness of less than 350HV10 is obtained (tested in accordance with AS 2205), or alternatively, with a higher hardness than 350HV10 it can be demonstrated that the joint is suitable for the intended service. It should be noted that the requirements of this clause (and Technical Note 1) will occasionally result in HAZ hardnesses in excess of 350HV10, but experience has shown the resultant welds to be satisfactory.

A fabricator desires to produce a single sided fillet weld (joint type F1 from Table 4.4(C)) in 20mm AS/NZS 3678 grade 350 steel. The flux cored arc welding process will be used with the following parameters:

→ 1.2ø, ETP-GCn-W504ACM1H_5 wire
→ 280 amps at 29 volts DC –
→ 350mm/min travel speed
→ CO_2 shielding gas with a flow rate of 17 l/min.
→ Electrical stickout 30mm.

The heat analysis on the test certificate reports the following major elements:

0.17% C, 1.19% Mn, 0.026% Ni, 0.019% Cr, 0.005% Mo, 0.008% Cu, 0.004% V

To calculate arc energy (Q), refer to clause 5.3.4(e)

$$Q = \frac{\text{Amps * Volts * 60}}{\text{1000 * Speed}} = \frac{280 * 29 * 60}{1000 * 350} = 1.39 \text{ kJ/mm}$$

Following the steps and calculations in Table A5.3 step 4 below, the minimum preheat required for an arc energy of 1.4kJ/mm in this joint configuration is 70°C†.

For the alternative method, calculate the Carbon Equivalent using formula (1) in clause 5.3.4(a)(ii).

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} = 0.17 + \frac{1.19}{6} + \frac{0.019 + 0.005 + 0.004}{5} + \frac{0.026 + 0.008}{15}$$

$$= 0.38$$

Add 0.01 to CE (0.38 + 0.01 = 0.39) and obtain the Weldability group number of "3" from Table 5.3.4(B)

Using this number in place of the above example means that the joint weldability index is now A thus referring to Figure 5.3.4(B), the preheat now required for an arc energy of 1.4kJ/mm is 0°C.

† Round up to the nearest multiple of 10° – see reference 3.

The practical difficulties in obtaining test material of the maximum carbon equivalent likely to be encountered in construction, which would be required to demonstrate satisfactory service performance, is such that it is recommended that the requirements of clause 5.3 be observed at all times. HAZ hardness tests are only required to qualify a welding procedure where the preheat temperatures do not comply with clause 5.3 (Note 2 to Table 4.7.1 of Part 1).

With the adoption in Australia of ISO 131916 as AS/ISO 13916 during 2003, the requirements of clause 5.3.3 covering the application and measurement of preheat were included in the 2004 edition of Part 1. Whilst Australian and New Zealand practice varies from the ISO recommendations, such variations were deemed to be of a minor nature and thus the ISO requirements were adopted within the AS/NZS 1554 parts.

A5.4 Welding Under Adverse Weather Conditions

The reasoning behind this clause is self-explanatory. Apart from the safety aspects, any welding carried out on wet surfaces may lead to welds which do not comply with Part 1. Unless adequate shelter is provided, windy conditions may lead to unacceptable welds due to loss of an effective arc shield. The same comment applies to gas shielded processes where the shielding gas can be blown from the arc region.

Table A5.3 Calculation of Preheat – Traditional Method

Step	AS/NZS 1554.1 Reference	Method	Working	Result
1. Select weldability Group	Clause 5.3.4(a) Table 5.3.4	Get steel grade	AS/NZS 3678 – 350	Group 5
2. Calculate combined Thickness	Clause 5.3.4(b) Figure 5.3.4	$t_1 + t_2 + t_3$ (simple fillet weld)	20 + 20 + 20	60mm
3. Establish joint weldability index	Clause 5.3.4(c) Figure 5.3.4A	Find closest intersecting line from Group number and joint weldability index	Group 5, 60mm combined thickness	Line D
4. Obtain combination of Arc Energy and Preheat	Clause 5.3.4(d) Figure 5.3.4(B)	From 3, find Arc Energy (Q) Input and Preheat combination line	Use Line D	For Q = 1.4 kJ/mm – 70°C † preheat

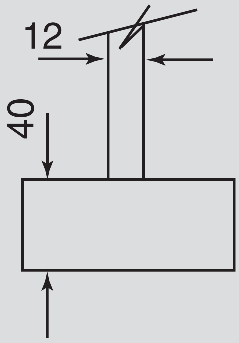
† Round up to the nearest multiple of 10° – see reference 3.

Other examples for the calculation of preheat are set out below.

Example (a) ***Plate girder – Web to flange fillet weld; MMAW, EXX24 electrodes***

Material – Web **AS/NZS 3678-250L15**
– Flange **AS/NZS 3678-250L15**
Group Number (Table 5.3.4) = 4
Combined Thickness (Figure 5.3.4(A)) = 12 + 40 + 40 = 92mm
Joint Weldability Index (Figure 5.3.4(A)) = C

Welding Parameters
Arc Voltage, E = 30 volts
Welding Current, I = 215 amperes
Welding Speed, v = 160 mm/minute
Heat Input Q $= \frac{30 \times 215}{160} \times \frac{60}{1000}$
= 2.4 kJ/mm of deposit
From Figure 5.3.4(C), no preheat is required.



Example (b) **As for (a) but SAW**
Submerged arc welding – parameters
Arc Voltage, E = 30 volts
Welding Current, I = 350 amperes
Welding Speed, v = 300 mm/minute
Heat Input Q $= \frac{30 \times 350}{300} \times \frac{60}{1000}$
= 2.1 kJ/mm of deposit
From Figure 5.3.4(C), no preheat is required.

Example (c) **Butt Weld between two plates, each 40mm thick; MMAW, EXX18 electrodes**
Material: **AS/NZS 3678-350L15**
Group Number (Table 5.3.4) = 5
Combined Thickness (Figure 5.3.4(A)) = 40 + 40 = 80mm
Joint Weldability Index (Figure 5.3.4(A)) = E

Welding Parameters
Arc Voltage, E = 25 volts
Welding Current, I = 215 amperes
Welding Speed, v = 150 mm/minute
Heat Input Q $= \frac{30 \times 215}{150} \times \frac{60}{1000}$
= 2.15 kJ/mm of deposit
From Figure 5.3.4(C), preheat temperature required is 50°C†.

Example (d) **As for (c) but SAW**
Submerged arc welding – parameters
Arc Voltage, E = 30 volts
Welding Current, I = 450 amperes
Welding Speed, v = 300 mm/minute
Heat Input Q $= \frac{30 \times 450}{300} \times \frac{60}{1000}$
= 2.7 kJ/mm of deposit
From Figure 5.3.4(C), preheat temperature required is 20°C†.

Example (e) From inspection of Figures 5.3.4(B) and 5.3.4(C) it will be seen that there will be no preheating requirement for at least the following cases:

Grade of steel (AS/NZS 3678 & AS/NZS 3679)	Hydrogen controlled process and consumables	Non hydrogen controlled
250,300 350, 400, 450	Q > 1.7 kJ/mm Q > 3.0 kJ/mm	Q > 2.3 kJ/mm Q > 4.2 kJ/mm

Other cases should be checked to determine what preheat (if any) is required

Figure A5.3 Examples of Determination of Preheating Temperatures

† Round up to the nearest multiple of 10° – see reference 3.

Similarly, unless the metal temperature is gradually raised above 0°C, welding on cold steel may lead to weld imperfections including cracks. Care should be exercised during flame heating with LP Gas as a fuel gas, since condensate may introduce moisture into the joint preparation.

A5.5 Tack Welds

This clause applies to tack welds which are incorporated in some form as part of the final weld. Temporary assembly tack welds are considered in clause 5.9 of Part 1. Both temporary and permanent tack welds must be of the same quality as the final welds in the structure. It is all too often assumed that because they are merely assembly welds, and therefore of no structural significance, tack welds do not require any particular care in welding. Unfortunately, there have been instances where weld fracture has resulted from cracks originating at tack weld locations.

Most cracks associated with tack welds are due to insufficient preheat being applied when tack welding is carried out. The use of hydrogen controlled welding processes such as the EXX16 or EXX18 type electrodes in MMAW, GMAW and FCAW (i.e. where weld metal hydrogen is guaranteed to be <15ml/100g of weld metal) is recommended for tack welding in order to minimise the possibility of HAZ cracking, and also to minimise preheat requirements.

Tack welds are seldom multi-run, but where these are necessary, the requirements of the clause for cascaded ends is intended to avoid the possibility of lack of fusion at the end of the weld where it is to be either incorporated in the final weld, or to be extended later during fabrication. It is also desirable to cascade ends in order to facilitate inspection and make it easier to incorporate into a final weld.

Limitations on tack weld minimum lengths have been fixed in order to avoid the situation where the welder merely applies a dob of weld metal to hold components together during assembly. These dobs are invariably applied without preheat and are often already cracked before being incorporated in the final weld. The limits given in clause 5.5 are the same as those in clause 3.3.3 and AS 4100, NZS 3404 or AS 3990 for intermittent fillet welds.

A5.6 Weld Depth-To-Width Ratio

The clause requires a minimum depth-to-width ratio of 1:1. Where the weld depth and maximum width exceed the width of the weld face, hot cracking can occur during welding of single run welds or in the early runs of multi-run welds (especially in the root run), or cold cracking may occur during cooling. These cracks are often not detectable by visual, magnetic particle, or liquid penetrant examination. It is commonly taken as good practice for SAW welds to use a ratio of depth-to-width of face of 1:1.5. Weld reinforcement should be disregarded though when measuring weld depth.

Whilst the possibility of welding successfully with depth to width ratios below the above figures is not excluded, freedom from cracking can not be guaranteed. It is therefore recommended that if such ratios must be used, that the fabricator carry out appropriate procedure tests using the worst case fit-up expected, combined with the expected degree of restraint. This should then be supplemented with an appropriate level of ultrasonic testing of affected weld joints to demonstrate freedom from centreline cracks.

A5.7 Control of Distortion and Residual Stress

A5.7.1 General

Distortion and shrinkage in a welded fabrication can be caused by a variety of conditions e.g. residual stress in hot rolled structural sections or plate, uneven amounts of weld material relative to the neutral axis of the member, etc. There are many published articles on control and/or correction of distortion and it is not intended to discuss the matter in any detail in this publication (References 12, 13).

It is usually better to control distortion during fabrication rather than be faced with removal of distortion after fabrication. Methods for control of distortion include planned sequences to balance heat input, use of subassemblies to reduce restraint in large weldments, and presetting and pre-cambering to allow for distortion. Some guidance on distortion control is also available in WTIA Technical Note 2.

A5.7.2 Welding and Cutting Under Stress

This clause merely requires that discussions be held between the principal or his representative and the fabricator to determine the methods to be used when welding members which are loaded, and are thus stressed to what may be a significant level. This situation is most likely to occur when strengthening and repairing existing structures. In particular, it is recommended that effects on the flexural and tensile member's cross-sectional area, and buckling in compression members is given due consideration as required by Appendix D of Part 1 so that the safety of the structure is not compromised. Further guidance is available in section 8 of AWS D1.1 which is entitled "Strengthening and Repairing Existing Structures". The following is based on these provisions and the commentary thereto.

Materials

The first essential requirement in strengthening and repairing existing structures is the identification of the material.

Weldability of the existing steel is of primary importance. Together with the mechanical properties of the material it will provide information essential for establishment of suitable welding procedure in accordance with Part 1. Should poor weldability make welding difficult or economically prohibitive, other means of joining have to be considered by the design engineer.

Material properties are normally assessed by chemical analysis of a small sample, metallurgical examination of a cross-section, and hardness testing, since there is usually insufficient material available for tensile testing. Once these properties are obtained, the suitability of the base steel for welding must be established.

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Steels that have been riveted, or structures that were designed for riveting, are of particular concern as these steel types were most likely produced when steel manufacturers had little control over sulphur or phosphorous. Elevated levels of these elements can make the welding of such steels difficult and expert assistance should be sought if welding is being contemplated.

Design

A complete engineering study of the stresses in the structures should be made if the operation extends beyond the restoration of corroded or damaged members. This is particularly important if the member has been subjected to cyclical loading.

Repair and strengthening of existing structures differ from new construction since they will have to be executed with the structure or the structural element under some condition of working stress.

There is presently little guidance with respect to welding of structural members under stress. Hence each given situation must be evaluated on its own merits, and sound engineering judgement must be exercised as to the optimum manner in which repair or strengthening should be accomplished. Stress levels for all in-situ dead and live loads will need to be established, together with consideration of accumulated damage that members may have suffered in past service.

Included in this assessment will be factors such as loads encountered during the repair/refurbishment process so as to prevent instability in the member and/or structure during the operation, whether existing connections can be used or need repair/reinforcing, and whether existing fasteners such as rivets or bolts are adequate or will be over-stressed.

Generally, in the case of dynamically loaded structures, sufficient data regarding past service is not available in order to estimate the remaining fatigue life. If such is the case, an inspection programme designed to locate possible fatigue cracks in stable growth prior to their becoming critical is a reasonable alternative.

The only practical methods of extending the expected fatigue life of a member in a given service is to reduce the stress or stress range, or to provide connection geometry less susceptible to fatigue failure. Examples of the latter include:

- *Profile improvement* – reshaping the weld profile with a carbide burr to obtain a smooth concave profile from the base material to the weld;
- *Toe grinding* – reshaping the weld toes by grinding with a burr or pencil grinder;
- *TIG dressing* – reshaping of the weld toe by the remelting of existing weld metal with heat from a GTAW arc.

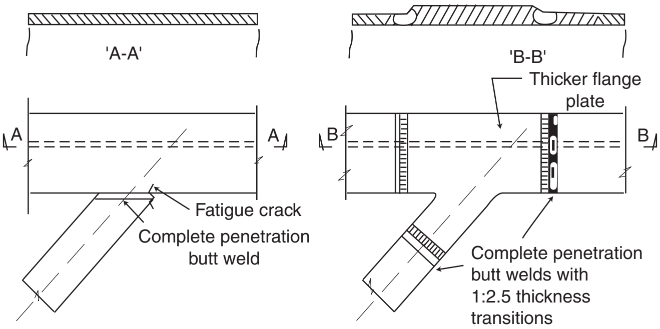

Figure A5.7.2 Location of Welds Away From Areas of Maximum Stress

To repair welds which are subject to fatigue failure requires a number of additional precautions. It is never satisfactory to simply weld up a fatigue crack, quite apart from the difficulty in obtaining a weld free from root defects. In a repair situation, the unsatisfactory load conditions which led to the original failure have been unaltered, and indeed may well have been intensified by the residual stress field around the repair. The use of peening techniques discussed in A5.7.3 may be useful in this regard. The practice of using cover plates to reduce stress in areas of fatigue cracking is completely unsatisfactory, since a welded cover plate represents a considerable stress raiser and invariably results in fatigue cracking occurring at the toes of the weld attaching the cover plate to the original member. A better alternative is to replace the original plate at the location of the crack by a thicker plate attached by suitably profiled welds located away from areas of maximum stress (see Figure A5.7.2). The use of surface peening and spot heating techniques should be also of value in increasing the fatigue performance of a member.

Workmanship

As with all weldments, it is important that surfaces of old material which are to be repaired or reinforced should be cleaned of dirt, rust, and other foreign matter except adherent paint film. Surfaces that are to be welded must be cleaned thoroughly of all foreign matter including paint film for a distance of 50 mm from each side of the outside lines of welds. Such surfaces, inside the areas cleaned for receiving welds, can be given a protective coating if required.

When the base metal is too thin to develop the required weld size or design capacity, it can rectified though:

1. build of weld metal to the required thickness;
2. cut back until adequate thickness is available;
3. reinforcement with additional base metal (noting the comments above); or
4. removal and replacement with base metal of adequate strength or thickness.

The most appropriate action from 1 to 4 though is best selected after consultation with the design engineer referred to above. In all cases welding and weld repair must be done in accordance with the relevant application Standard.

In strengthening or repairing members, either through the addition of base metal of weld metal, or both, it is important that all welding be done in such a way as to balance the heat input about the neutral axis of the member so as to minimise distortion and residual stress. This is of particular importance if live load is permitted upon the structure while the member under consideration is being strengthened or repaired.

A5.7.3 Peening

Whilst useful in reducing residual stress, distortion and cracking, peening is seldom used in original fabrication, but finds application in repair techniques. The amount of peening carried out should only be sufficient to counteract the weld shrinkage and care should be taken to ensure that is not used to caulk over cracks or other defects.

The provisions of the clause are such as to ensure the peening is acceptable for the application for which Part 1 is employed. Considerable care should be exercised in adopting and carrying out any peening procedure.

The main reasons for avoiding peening are that peening could:-

(i) crack root runs without the cracks being detected;

(ii) produce a notch due to the blows being too hard;

(iii) cause overlap (i.e. over-roll of weld runs due to the spreading of material during) of weld runs, which could subsequently be covered undetected by later runs.

The clause has been written to avoid (i), and to avoid (ii) in surface welds or parent metal. Provided the correct peening procedure has been adopted, it is considered that any minor notches in intermediate weld runs will be consumed in later runs and hence (iii) will be avoided.

It is emphasised that some care is necessary in establishing peening procedures.

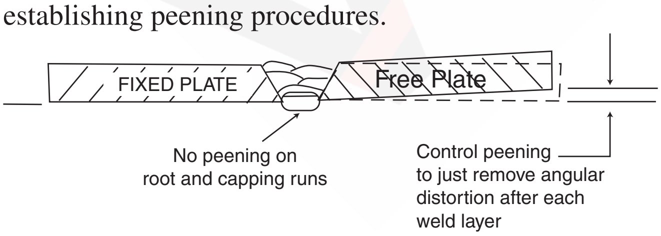

Figure A5.7.3 Calibration of Peening Procedure

Where peening is to be employed, it is suggested that the procedure be calibrated by means of a test piece as shown in Figure A5.7.3. Using a pneumatic chisel fitted with a rounded tip (generally 6 or 10 mm in diameter), or a flat tip, and with the air pressure controlled, determine the time per length of weld required to restore the free plate to an acceptable level of flatness for each layer of weld. Peening is not permitted on the root or final runs of the weld.

The clause does not cover the use of peening on weld toes for improvement of fatigue performance.

The use of peening is subject to agreement between the principal and the fabricator.

A5.7.4 Correction of Distortion

The methods outlined in this clause are considered to be acceptable means of correcting distortion, but all of them require some care in their application.

Mechanical methods are usually applicable where distortion affects the entire weldment about one axis only. It is not usually applicable to localised distortion such as may be encountered in a web panel of a stiffened three-plate girder. In such a case, flame straightening (controlled heating) would be the preferred method.

The location direction of the heat application must be carefully assessed before distortion correction is attempted.

Ill-considered procedures can lead to a worsening of the situation, often to the point where no alternative is left but to remove the affected part and start again. This in itself can lead to further shrinkage and distortion problems.

The controlled application of weld runs, presetting and pre-cambering, are used more to control distortion than to correct it. The controlled application of weld runs is the method that would be used during welding of unsymmetrical sections or where weld volumes are unevenly located relative to member axes.

Although the use of solid water jets for cooling is suggested, this method of correcting distortion is fraught with difficulty and its use is not recommended. Water spray cooling is an acceptable alternative but care is required with its application. Few fabricators in Australia have experience with either method.

Once temperatures of steel exceed about 650°C they approach those applied for normalising steel and the danger exists that the mechanical properties of the steel may alter, hence the limitation of 600°C.

Note: *Over the last decade, steel making and rolling technologies have improved to the point that steel alloy compositions have been greatly reduced, thus enhancing weldability and formability of structural steels. As some of these steel types will soften quickly if over-heated, the fabricator should seek advice from the steel manufacturer prior to commencing flame straightening.*

A5.8 Backgouging and Repair of Defects in Welds

A5.8.1. General

Of all the possible contentious contractual issues, the repair of faulty welds is probably one of the greatest sources of disagreement. Part 1 is intended to eliminate, as much as possible, such disagreement by fixing permissible levels of imperfections which can be tolerated in welds subject to various levels of service prescribed in Part 1. Despite this, there will still be occasions when the principal, or his representative, or the inspecting authority, and the fabricator will find reasons to discuss whether a weld with imperfections exceeding those specified in Tables 6.2.1 and 6.2.2 should be repaired, or removed and replaced in its entirety.

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Part 1 does not specifically state who nominates whether weld imperfections are acceptable within the limits set in Table 6.2.1 and 6.2.2. Normally the inspector would nominate the acceptability or otherwise of a weld on behalf of the principal, but in some cases it is the inspecting authority which nominates the acceptability or otherwise. If the weld imperfections exceed the permissible levels in Tables 6.2.1 and 6.2.2, the principal, or his representative, or the inspecting authority should ascertain whether the proposed repair or replacement will not be more injurious to the performance of the weldment than the weld defect itself, and should be prepared to consider acceptance of non-complying defects in accordance with clause 6.7 of Part 1.

A5.8.2 Removal of Weld Metal

With regard to removal of weld metal, the requirement of the clause to avoid nicking or undercutting of remaining weld metal or base metal is aimed at eliminating the possibility of notches or areas of lack of fusion being built back into the repaired weld.

Substantial removal of the base metal is not only uneconomical in terms of unnecessary weld repair, but could also lead to shrinkage and distortion problems due to the large localised heat input from an excessive amount of weld metal.

A5.8.3 Grinding

This clause only applies to grinding of already completed welds to remove undercut or other imperfections. The requirement for smooth blending of the surrounding surface is to avoid the possibility of notches. In addition, grinding of welds for aesthetic appearance of the surface of the steel may also be required. If so, this should be stated in the specification. The restriction on depth of grinding below the surface of the parent metal is a requirement intended to restrict the loss in cross-sectional area of the parent material.

A5.8.4 Stop Starts

Specific repair requirements were inserted into the 2000 edition of Part 1 to provide guidance to the fabricator on the repair of stop starts in welds that may experience higher levels of dynamic loading that other weld categories. The procedure recommended is specifically designed to minimise the presence of stress concentrators. The requirements for stop starts in joints in rolled hollow sections (RHS) was further clarified in the 2004 edition (Reference 7).

A5.9 Temporary Attachments

The reason for the requirements of the clause in respect of the welding of temporary attachments has been discussed in A5.5.

Similarly, it is also important that only those competent to understand all the loads and how the joint will function can approve their use. It is not uncommon for a temporary construction or transport aid to be welded without due consideration being given to design requirements or thought for added loads including load concentration effects, wind, water, loose stock during transport, erection loads etc. In such circumstances, the risk of failure can be high with resultant risks to the health and safety of fabrication, construction and transport personnel (note also the requirements of Clause 1.8.3 of Part 1). Minimisation of these risks is difficult to achieve in practice unless compliance with the requirements of Part 1 of AS/NZS1554 and those of the relevant design Standard is maintained.

Temporary welds and attachments on tension flanges of beams and girders, particularly welds oriented transverse to the direction of major stress in the flange, are potential initiators of fatigue cracks and/or brittle fracture. Hence, such welds are not permitted. No such restriction is implied on permanent attachments such as brackets or stiffeners.

Note: *It is the responsibility of the designer to clearly indicate such critical locations so the fabricator can comply with this clause.*

The requirements for the reinstatement of surface from which temporary welds or attachments have been removed is intended to minimise the likelihood of macro cracks initiating from gouges, notches or micro weld cracks.

A5.10 Arc Strikes

Arc strikes may produce small craters containing cracks in the surface of the steel. These, particularly in members subject to dynamic loading, are potential initiating points for fatigue cracking or brittle fracture.

A6 Quality of Welds

A6.1 Categories of Welds

All welds made in accordance with Part 1 must be designated by the design engineer as either GP or SP weld category. Clause 1.6 of Part 1 gives guidance as to the basis on which this selection is done. In setting the levels of imperfections for each weld category, Part 1 relies on the fact that it does not apply for the most severe cases of fatigue loading and is only intended to be used where parent materials and weld metals have been selected to avoid the risk of brittle fracture (see A1.1). The failure mechanism considered in Part 1 is that of ductile failure by tensile overload, whatever the cause of the tensile over-load, be it static or fatigue loading. The influence of weld defects on this mode of failure is well documented and approximates the loss of load bearing cross-sectional area (References 14, 15). Weld category SP is based on a maximum loss of cross-sectional area of 5% and weld category GP on a maximum 10% loss of cross-sectional area, each of which incorporates a substantial margin of safety under the conditions envisaged in Part 1. It must be remembered, however, that Part 1 is based upon minimum levels of non-destructive testing after welding, and that the security of the welded structure relies heavily upon adherence to qualified welding procedures, the inspection of weld preparations prior to welding followed by visual inspection after welding.

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A6.2 Methods of Inspection and Permissible Levels of Imperfections

A06.2 General

Depending upon the type of application and the weld category, welds may be specified to be inspected by visual means only, or visual (or other means) augmented by radiographic or ultrasonic examination. Guidance on levels of inspection recommended to be carried out for typical applications is given in section A0 of this commentary. Section A0 (in line with the provisions of Part 1) recommends low levels of inspection by means other than visual and also suggests 100% visual scanning (not inspection) of all welds.

Where visual inspection (with or without magnetic particle and liquid penetrant inspection) is carried out, the evaluation of the acceptability of the weld in terms of Table 6.2 of Part 1 is strongly recommended to be augmented by using the macro test specimen from the procedure qualification (see A6.2.2(ix)). Whilst the method of visual inspection is not specified in Part 1, the use of AS 3978 is recommended.

Where radiographic or ultrasonic examination is also used, the evaluation of the acceptability of a weld in terms of Table 6.3 of Part 1 is required to be carried out using a specified compliance procedure (see A6.3 and A6.4).

NDE technicians and fabricators alike should also be aware of the time dependent nature of hydrogen cracking in particular and allow sufficient time to elapse after the cessation of welding before conducting NDE examinations to detect the presence of developing cracks. A minimum of 48 hours is preferred, but should not be less than 24 hours ((Reference 11).

For information on general inspection requirements, refer to section A7 of this commentary.

Note: *The reader should be especially aware that surface breaking imperfections regarded as acceptable under the requirements of this section may be deemed rejectable if their presence conflicts with any surface treatment requirements. Where it is necessary to remove such imperfections to avoid conflict with surface treatment requirements, if the removal of the imperfections reduces the cross sectional area by more than 5% for SP or 10% for GP category welds, the weld must be repaired in accordance with clauses 5.8 and 6.7 of Part 1.*

A6.2.1 Methods of Inspection of Completed Welds

Part 1 requires that welds be visually inspected for compliance with the requirements of Table 6.2.2. It is not intended to imply that the complete length of all welds be subjected to a detailed visual inspection, and section A0 gives guidance on the appropriate percentage of detailed visual inspection. More general visual inspection (visual scanning), without close examination to Table 6.2.2 is necessary for all lengths of weld (clause 7.3).

Part 1 permits visual inspection to be supplemented by magnetic particle and liquid penetrant inspection. These methods are considered only appropriate in this supplementary role or in special conditions, such as the examination of weld repair.

Other forms of non-destructive testing, such as radiography and ultrasonics, are considered appropriate only for weld category SP and the levels of imperfection measured shall comply with Table 6.2.1. It should be noted that often these techniques are the only reliable forms of inspection to verify the internal structural integrity of a joint. However, to produce the desirable results these methods require specification of method, such as X-ray or Gamma-ray in the case of radiography, or probe type and level in the case of manual ultrasonic inspection, and probe type and nominal angle for automated ultrasonics. Where such non-destructive testing is required by the principal, it is to be specified in the drawings and preferably also in the tender documents. Advice should be sought if the specifier (usually the design engineer) is unclear about these requirements (see also sections A6.3 and A6.4).

A6.2.2 Permissible Levels of Imperfection

Table 6.2.2

Table 6.2.2 of Part 1 details the permissible levels of imperfection revealed by visual, magnetic particle or liquid penetrant examination.

The levels of permissible imperfections given in Table 6.2.2 are essentially derived from consideration of what constitutes good workmanship, and are related to the previous editions of the Standard and experience gained in using these earlier editions.

The levels of permissible imperfections of Table 6.2.2 are also related to the intended range of application of each weld category.

In relation to Table 6.2.2, the following explanatory comments are offered:-

Fillet Welds

There is no restriction on reinforcement for GP category fillet welds, since the shape of such welds does not influence their performance. SP category fillet welds, on the other hand, are restricted in terms of the amount of reinforcement permitted, since excessive reinforcement may mask other more serious imperfections.

Butt Welds

(i) *Cracks:* Minor weld crater cracks are permissible in GP category butt welds up to a maximum crack length of 6 mm in any metre of weld; no cracks are allowed in SP category butt welds. It is suggested that minor tearing not exceeding 0.5 mm in any direction should not be regarded as cracks for both SP and GP category butt welds.

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(ii) *Lack of Fusion or Incomplete Penetration:* It is important to note that any lack of fusion or incomplete penetration detected should be included in the loss of area calculation (see (ix) below). For SP category welds, a maximum length of 2*t*/3 up to a maximum of 20 mm total is permitted as a general provision in areas more than 3*t* from the free ends of butt welds, and 3 mm maximum length closer than 3*t* to the free ends of butt welds. The maximum aggregate length permitted is *t* in 6*t*.

The free end of the weld corresponds to the end of a weld not incorporated into any other weld. Ends of butt welds incorporated into other welds at joints, such as T-junctions, need not be considered as free ends for the purpose of this clause.

In cases where visual examination reveals a critical level of an imperfection(s) and the depth of the lack of fusion or incomplete penetration cannot be easily determined, a supportive examination using ultrasonics should be carried out in the region(s) of interest as covered in section 6.4 and the corresponding Table 6.2.1. Although ultrasonic examination using the Time Of Flight Diffraction technique is not yet permitted by the Standard, it is a very reliable method for accurate sizing of imperfections and its use should be seriously considered and discussed with the Principal in such situations.

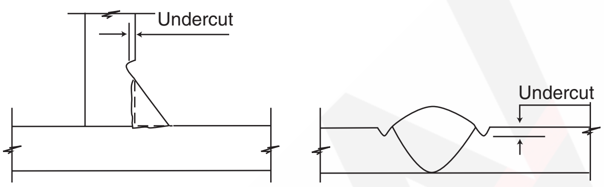

Figure A6.2.2.1 Undercut in Butt and Fillet welds

(iii) *Undercut* – Continuous and Intermittent: Undercut is not considered particularly detrimental for the service conditions envisaged under Part 1, and therefore fairly generous limits have been allowed in order to eliminate the need for unnecessary repairs. It is suggested that undercut less than 0.5 mm in depth may be disregarded for both SP and GP category butt and fillet welds. Undercut on a weld must be considered when estimating the loss of load bearing cross-sectional area.

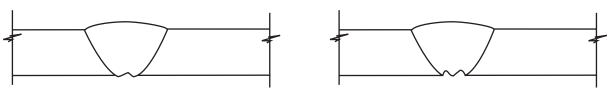

Figure A6.2.2.2 Root Concavity and Shrinkage Grooves

(iv) *Shrinkage Grooves and Root Concavity (Figure A6.2.2.2):* The same comments as in (iii) apply. Shrinkage grooves and root concavity must be considered when estimating the loss of load bearing cross-sectional area.

(v) *Reinforcement:* As with SP fillet welds there are limits place on reinforcement for SP category butt welds although they are more liberal.

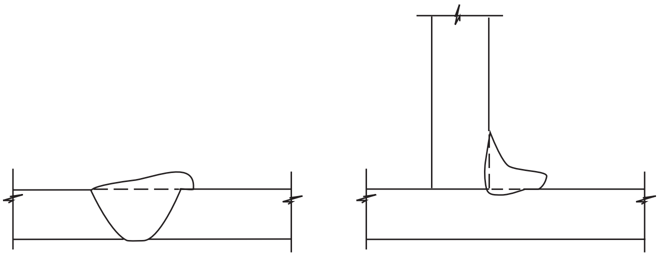

Figure A6.2.2.3 Overlap

(vi) *Overlap (Figure A6.2.2.3):* Restrictions are placed on the length of weld overlap (roll-over) in order that this relatively insignificant defect does not conceal significant amounts of other imperfections. This imperfection also has the potential to act as a stress raiser in dynamic loading situations (i.e. SP quality welds), thus should be controlled.

(vii) *Toe-shape:* No limitation other than that for overlap is placed on the toe-shape for GP category welds, while for SP category welds, the only requirements is that the weld profile permits any non-destructive examination that is required to be carried out.

(viii) *Surface Pores:* The maximum size of surface pores in GP category welds is not limited, but the total number is limited to 6 in any 12*t* of weld length. For SP category welds a maximum pore size of *t*/3 up to a maximum of 5 mm diameter is permitted but only 2 surface pores are permitted in 12*t* length of weld. It should be noted that these levels of exposed porosity may cause problems with corrosion protection and may be subject to other stringent requirements for this reason.

(ix) *Loss of Cross-Sectional Area:* In Table 6.2.2, the maximum loss of load bearing area is limited to 10% for GP category welds, and to 5% for SP category welds. In the calculation of the loss of cross-sectional area, lack of fusion, undercut, shrinkage grooves, root concavities and in some cases misalignment are included. In general, it is usual to disregard porosity in determining the loss of cross-sectional area.

In the case of a welding procedure qualification, the macro test specimen should be used to estimate the influence of imperfections, present in the plane of the cross-section, on the loss of cross-sectional area (see clause 6.2.4 of Part 1).

Should the welding procedure with its corresponding macro test piece not be available to determine the specific cross section, a potential loss in cross sectional area greater than the 10% for GP or 5% for SP can be determined as follows:

1. Establish the level of compliance for each individual imperfection listed in Table 6.2.2 that contributes to loss of cross sectional area such as cracks, lack of fusion, undercut, misalignment.
2. Identify the locations along the weld where the sum of overlapping individual imperfections exceed a loss of 10% for GP or 5% for SP category welds (the inspector will most likely be aware of where this will be the case as each weld should have already been inspected for the individual imperfections).

As with the individual assessment of an imperfection, should the inspector be unsure about the actual depth of the imperfection (especially in critical cases), it is appropriate to call for ultrasonic examination in accordance with section 6.4 of Part 1 and assess the depth and length of the imperfection to Table 6.2.1.

Where the loss of cross-sectional area complies with Table 6.2.2, the weld should be considered satisfactory in terms of Part 1 and no further action is necessary. Where the loss of cross-sectional area does not comply with Table 6.2.2, the fabricator has the option of either:-

(a) repairing the weld in accordance with the provisions of Part 1 at any one location were the loss of area exists, or if necessary at more than one location of the contributing surface imperfections so that compliance is established;

or

(b) demonstrating that the imperfection(s) will not be injurious to the structure under clause 6.7 of Part 1.

If any individual imperfection exceeds the permissible level of Table 6.2.2 the fabricator may either repair the weld or use method (b) above.

A6.3 Radiography

The 1980 edition of the Standard introduced a new method of assessing acceptability of welds in terms of Loss of Area. This method required the availability of the procedure qualification macro and a multi-step assessment process when imperfections were located.

Some operators found difficulties with the system although others found it to work well and achieve the aim of reducing needless repairs.

As a result of these problems, the 1985 edition of Part 1 was changed with respect to the assessment method, although the basic concept of a maximum loss of area of 5% in SP category welds was maintained. This has been carried through into AS/NZS 1554.1 2000.

The question of which radiographic technique to be applied requires specialist knowledge and if unsure the advice of experts should be sought. It is well possible that while one technique properly applied could show a defect, the other may not. As noted in AS/NZS 1554.1, guidance on how to perform the inspection is given in AS 2177.1. In general terms, X-ray technology provides a wider range of applicability, however is more restrictive in its application due to the size of the equipment. Gamma-ray technology is easier to apply and is therefore sometimes used despite not having the ability to show certain problems. This especially applies for thinner materials and XR2 techniques are preferred to maximise the likelihood of detecting cracks (GR 2 may be used by mutual agreement). Radiographic sensitivity is expressed in terms of visible IQI wire seen in the radiograph rather than absolute percentage.

Since the basis of the acceptance criterion is a maximum loss of area, and since it is difficult to determine the through thickness size of an imperfection by radiography, it is assumed that any defect detected is 2 mm in height unless there is evidence to the contrary. Suspect areas may, by mutual agreement, be re-examined by ultrasonic examination in which case the ultrasonic results take precedence over the radiographic examination.

A6.4 Ultrasonic Examination

Ultrasonic examination requires considerable expertise and to correctly specify the technique and its extent of use, the specifier should have an understanding of the testing technique, or seek expert advice. The following is a brief description on some of the techniques available.

a) **Reflectivity Method**

The standard uses a reflectivity method of assessing defect severity, and to ensure repeatability of testing it was necessary to standardise the method of testing.

This was done by specifying probe size and frequency for specific conditions and requiring that planar defects be measured with an angle of incidence less than 10° or with an appropriate gain increase for angles of incidence between 10° and 20° (Table 6.4.2). Since the angles of incidence are not actually known at the time of test, the basis for determination of appropriate probe angles is the welding procedure. The welding procedure should therefore be made available to the testing technician. The evaluation levels specified in section 6.4.2 should be used unless specified otherwise.

The ultrasonic examination method laid out is primarily concerned with the largest discontinuity that might be missed, not the smallest that can be detected. Low frequency probes give more beam spread than high frequency probes and therefore planar discontinuities such as cracks will give a broader beam spread particularly from the crack's tips, thus giving the NDE Technician a greater probability of detecting an unfavourably oriented planar discontinuity. Once found, high frequency probes can then be used to accurately locate, characterise and size the defect.

Acceptance limits are the same as radiography (Table 6.2.1).

b) **Automated Ultrasonics**

AS 2207 does not preclude the use of automated ultrasonic examination if the specific requirements are satisfied, and this is achievable with automated pulse echo techniques. The standard permits the use of automated ultrasonics as a substitute for conventional manually manipulated probe ultrasonics. Testing methodology is based on British Standards developed over the past two decades.

- **Pulse-echo Techniques**

Automation of probe location and data acquisition using conventional reflectivity based pulse echo techniques has been shown to result in increased productivity, probability of detection and reliability of the ultrasonic inspection process.

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- **Time of Flight Diffraction**

  TOFD provides a longitudinal cross section representation of the discontinuities within a weld. The output has parallels with a conventional radiograph with the same advantages of providing an image of the discontinuities detected. Probability of detection is very high and false call rate is very low. Information on length, height, through thickness location and type of discontinuity can be provided. Surface breaking discontinuities such as lack of root fusion, lack of penetration and undercut can be detected and accurately sized. This satisfies the requirement of AS/NZS 1554.1, AS/NZS 1554.4 and AS/NZS 1554.5 to quantify the loss of cross section due to weld discontinuities. TOFD is particularly suited to AS/NZS 1554 and its parts, which are fitness-for-purpose based Standards rather than workmanship based Standards. AS/NZS 1554.1 is a world leader in this respect.

  TOFD can provide a permanent hard copy record as evidence of a test. The record also allows third party and independent assessment of test results after data collection. Data from a test can be used to illustrate that a particular weld was tested and also verify the amount of weld that was tested. A repeat survey of a selected area should indicate the same discontinuity "signature".

  It should be noted that AS 2207 does not currently cover the use of the TOFD technique, thus any consideration for its use in AS/NZS 1554 applications should only occur after discussion with the Principal or relevant Inspection Authority.

Irrespective of what ultrasonic test method is used, the weld is to be assumed to be divided into a number of approximately equal lengths each not exceeding 1.0m in length and each assessed independently. Where continuous or adjacent imperfections cross the division between the examination lengths, the examination length is to be relocated to include the most severe combination of imperfections. In this respect the 1985 and subsequent versions of the Standard are more conservative than the 1980 version in requiring each individual metre of weld to adhere to the 5% Loss of Area requirement rather than the weld as a whole.

A6.7 Weld Defects

Imperfections in excess of those specified in Part 1 may, with the approval of the principal, be acceptable subject to a satisfactory fracture mechanics assessment of the structure (note the guidance note above regarding surface treatment limitations). Publications such as the WTIA's Technical Note 10 and the British Standard BS 7910 give guidance on how this assessment may be carried out, however such assessments are usually best left to specialists trained and experienced in the application of Fracture Mechanics. In general, however, it will be preferable to adhere to the provisions of Part 1 in the manufacture of most new structures, and restrict the use of fracture mechanics techniques to structures where repair is impractical.

In all cases, repaired welds should be reinspected using an appropriate NDE method, the very least being the original method specified and used.

Imperfections of plate origin in the weld zone (including the heat affected zone) are not normally considered cause for rejection. This clarification was inserted as Amendment 1 in 1998 because of confusion occurring when inclusions of steelmaking origin deemed satisfactory under AS 1710 were considered rejectable by some inspection personnel when they did not meet the more stringent requirements of AS/NZS 1554.1. This amendment does NOT apply to lamellar tearing imperfections as they are regarded as being of weld origin even though the cracking occurs in the plate (see WTIA Technical Note 6).

The last two points were added to the Standard in 1998 (by way of Amendment No1) to clarify these issues.

Note: *As noted in section A1.1 of this commentary, in the absence of any guidance in Part 1 as to acceptable levels of defects resulting from lamellar tearing, it is suggested that the plate edge defect rules in AWS D1.1 (section 5.15.1) be used. For further information on lamellar tearing, please refer to WTIA Technical Note 6.*

A7 INSPECTION

A7.1 General

Inspection is intended to ensure that the specified requirements of the principal with regard to materials and workmanship are met. Most weldments are inspected on behalf of both the fabricator and the principal through their representatives.

Occasionally, inspection and testing on the over-all fabrication (including site work) may, at the principal's request, be governed a document known as an inspection and test plan (ITP). If an ITP is required, it will be specified in the contract. The plan is drawn up by the fabricator's quality section and provides an agreed schedule and level for tests and inspections to jointly serve the needs of the fabricator, principal and inspection authority. Guidance on ITPs is available in WTIA Technical Note 19.

Welding Supervisors employed by the fabricator for quality control, are responsible for checking materials, equipment, dimensions and workmanship. Quite often the Welding Supervisor will have other duties such as foreman, unless the fabricator has sufficient capacity to warrant a full-time supervisor.

This type of inspection is essentially internal quality control inspection for the fabricator's own purposes and as such, it does not come within the provisions of Part 1. It is in the fabricator's best interests to ensure that any welding carried out will comply with the requirements of Part 1, but the Standard intentionally does not require any inspection by the fabricator.

Inspectors employed by the principal perform essentially the same inspection duties as the Welding Supervisor mentioned above. Because of the nature of the employment, the inspector may have to work in several locations on several different projects. Accordingly, the fabricator is required to give “reasonable notice” so that the inspector may arrange the inspection programme accordingly. It is normal procedure for the inspector to make regular visits to ensure that work is being carried out in the prescribed manner; access should therefore be provided on a reasonable basis by the fabricator.

By the same token, the inspector should endeavour to carry out inspections as expeditiously as possible so that the welding operations are not delayed.

The inspector is permitted access to the work whenever “reasonable” – that is, whenever the provision of such access does not intentionally delay the welding operations. Means of access such as ladders should be made available by the fabricator, but equipment required by the inspector for carrying out an inspection should be provided by the inspector unless satisfactory arrangements can be made with the fabricator.

A fundamental requirement of Part 1 is that a qualified welding procedure is used by qualified welders, therefore it is important that the inspector be fully satisfied that all necessary qualification tests are carried out or that satisfactory documented evidence is available to indicate the adequacy of the welding procedures to be used.

The duties and responsibilities of the inspector are stated in clause 7.3 and 7.4 of Part 1. The quality assurance function is performed by the inspector for the principal and thus is responsible under Part 1 to ensure that the work is performed in conformity with its provisions, expressed as either acceptance or rejection of the fabricator’s work.

Unless the contract states otherwise, the inspector has no authority under Part 1 to stop the work if the fabricator elects to proceed even after he has been informed that either materials, processes, welder qualification, workmanship, or other provisions relating to the contract are unacceptable. However, proceeding with unacceptable practices may lead to rejection and to extensive repairs.

The fabricator may undertake repairs to welds inspected by the Welding Supervisor without the specific approval of the inspector providing this work complies with the requirements of Part 1. In such instances the inspector should be informed of any substantial repair undertaken including repairs to distortion. The inspector may require notification, before repair, of any incidence of cracking.

Drawings, specifications, and other pertinent contract documents relating to weldments to be inspected must be made available to the inspector by the principal. When an inspector finds that incorrect or defective material, improper procedures, inadequate equipment, or unqualified personnel are being proposed or being used for welding, he should inform the fabricator and the principal at the earliest practical opportunity.

Materials or workmanship not conforming to the requirements of Part 1 should be rejected unless subsequently corrected by approved methods. Minor corrections and changes required by the inspector are normally agreed to on the job. Where major changes are proposed by either the inspector or fabricator the approval of the principal should be sought.

In general, inspection should be performed in sequence with the manufacturing operations e.g. as may be set out in an inspection and test plan drawn up by the fabricator and endorsed with the inspection levels desired by the principal. There are four reasons for this recommendation:-

(i) interference between inspection and production is kept to a minimum;
(ii) inspection status is recorded and delayed or double inspection is avoided;
(iii) in order that inspection operations required at a certain stage of fabrication can be completed (such as when completion of the next manufacturing step would make inspection of the proceeding one impossible);
(iv) timely inspection gives earliest feedback on the success of procedures and operations.

The following order of welding inspection operations is suggested as a general guide to the inspector. It should be understood that the actual operations and the order in which they are applied will depend upon the type of weldments, the method of manufacture, and the requirements of Part 1.

The following sequence is suggested (based on Reference 16):-

Procedure Inspection

– Prior to Production Welding
 Check of certificates for Parent Material
 Check materials and consumables identity
 Check welding procedure and welder qualification
 Approve Welding Procedure Sheets where specified in the contract
 Check welding and allied fabrication equipment
 Review quality plan and/or inspection and test plan

– Base Metal Defects
 Laminations and cracks (laminations may be more apparent after cutting)
 Surface irregularities
 Flatness

– Joint Fit-up and Material Preparation
 Edge preparation (including root face and bevelling) and
 roughness
 Dimensions
 Cleanliness
 Assembly including alignment and gap
 Tacking
 Backing (where required)

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– During Welding
  Preheat and inter-run temperatures (if required)
  Root run
  Root preparation prior to welding second side
  Cleaning between runs
  Appearance of runs
  Variations from approved welding procedures (current† , etc.)
  Welders are qualified

Acceptance Inspection

– Non-destructive Testing
  Dimensional inspection
  Visual inspection
  Surface appearance of welds
  Conformity of welds with drawings
  Time delay requirements for detection of time dependent imperfections (Reference 11)
  Magnetic particle and liquid penetrant test
  Radiography
  Ultrasonic tests

– Repairs
  Marking of acceptance or rejection
  Inspection after repair

The recommended procedures in respect of the costs of inspection are as follows (note item 's' in Appendix D of Part 1 Matters for Resolution):-

(i) the principal pays for the cost of inspection, and engages the inspector and any non-destructive testing personnel required. The extent and nature of the NDE should be dealt with in the contract documents.

(ii) the fabricator should repair defective welds at his own expense and pay for any testing of the repaired welds which may be required by the principal.

It is also reasonable to have included in the contract documents, items detailing the qualifications of non-destructive testing personnel (see A7.4)

A7.2 Qualifications of Inspectors

As much of the steel fabrication involves the cutting and welding of steel, it is important that the inspector should have had practical experience in these fields and be familiar with the requirements that govern the work to be inspected. Welding inspectors should be qualified to at least the same level as the Welding Supervisor (see discussion in section A4.12.1). The WTIA Welding Inspector Certificate and CBIP Inspector Certificate offers evidence of qualification, as does the AS 2214 Welding Supervisor Certificate, and these three qualifications are deemed to be acceptable.

The inspector should be conversant with:-

(i) welding equipment materials and processes, and their limitations;
(ii) joint preparations;
(iii) welding procedures;
(iv) fabrication methods and equipment
(v) non-destructive testing and interpretation of results;
(vi) weld imperfections and methods of correction.

The inspector should also be familiar with the quality of work required for both SP and GP category welds. The ability to interpret the requirements of Part 1 and to assess compliance with the requirements of Part 1 are the most important qualifications.

A7.3 Visual Inspection of Work

Having accepted or established a qualified welding procedure involving a joint preparation, welding consumables and preheat, it is most important that the inspector visually check that the edge of the preparation meets the requirements for workmanship in clauses 5.1 and 5.2 of Part 1, and he must ensure that the welding procedure executed is that laid down in the qualified welding procedure. If all of this is not done, the quality control procedures on which part 1 are based may breakdown.

During welding and once the welding is completed, the inspector must then:-

(i) ensure that the workmanship provisions of section 5 are met;
(ii) visually inspect the weld to the extent specified in the contract to ensure compliance with clause 6.2;
(iii) arrange for any other non-destructive examination that may be required, in accordance with clause 7.4.

Although Part 1 does not require it, it is important that the inspector identify welds that have been inspected and accepted, while welds inspected but rejected for any reason, should also be separately identified. All identifying marks used should be agreed between the inspector and fabricator. A weld map may be used for this purpose (see WTIA Technical Note 19).

Visual inspection cannot disclose internal discontinuities in completed welds. When non-destructive examination techniques such as radiography and ultrasonics are not specified in the contract document, it must be assumed that the procedure qualification and other inspection and workmanship requirements of Part 1 will produce a weld of adequate quality of the intended purpose.

Whilst not a requirement of Part 1, the use of AS 3978 to provide guidance on visual inspection requirements is recommended.

Note: *The inspector should be especially aware that surface breaking imperfections regarded as acceptable under the requirements of clause 6.2 may be deemed rejectable if their presence conflicts with any surface treatment requirements.*

A7.4 Non-Destructive Examination Other Than Visual

A07.4 Qualification of Personnel

It is essential that personnel responsible for the execution of any non-destructive examination required by the contract be experienced in examining welds by the means specified in the contract.

† The inspector should use calibrated external meters or tong testers to measure the actual amps and volts being used by the welder(s) during fabrication.

It is recommended in this commentary that such examination be carried out:-

(i) by a laboratory service accredited by the National Association of Testing Authorities (NATA) in Australia or International Accreditation New Zealand (IANZ) in New Zealand for the particular method being used; and

(ii) by an individual operator from that laboratory service, qualified by the Australian Institute of Non-Destructive Testing (AINDT) or the Certification Board for Inspection Personnel (CBIP-NZ) in New Zealand to carry out the particular NDE method to the requirements of Part 1.

These organisations (NATA & AINDT and IANZ & CBIP-NZ) operate complementary schemes which have the following features:

(a) a laboratory accreditation scheme operated by NATA and IANZ which concerns itself with the overall performance of a laboratory having regard to the abilities of the individual staff members for whom it sets specific requirements according to their individual responsibilities within the total laboratory function. Recognition of ability and performance of an individual relates only to their operations as a direct part of the total laboratory performance.

(b) a scheme for qualification of inspection personnel in any working environment irrespective of employment association. AINDT and CBIP-NZ achieve this objective through an assessment of candidates basic abilities, NDE method, practical experience, theoretical knowledge and general knowledge of inter-relationship between various NDE methods. AINDT and CBIP-NZ set written practical and oral examinations for the purpose of assessing inspection personnel when investigation of other local or overseas qualification do not fulfil its requirements.

This scheme qualifies in method:–

(i) radiographic;

(ii) ultrasonic; and

(iii) magnetic particle and penetrant examination:

At three levels of completion

(i) technical assistant;

(ii) technician; and,

(iii) technologist.

AINDT (through AS 3998) offers certification of NDE personnel at levels 1, 2, and 3 in the relevant NDE inspection discipline that meets the requirements of ISO 9712. CBIP-NZ operates a similar certification system that generally meets the requirements of ISO 9712.

The terminology applied and the standards of performance and capability, and experience required, are comparable with the requirements for similar recognition in the NATA and IANZ scheme of laboratory staff and performance accreditation.

A list of laboratories accredited by NATA and IANZ for testing of metals and welds is obtainable from the National Association of Testing Authorities for Australian laboratories, and IANZ for New Zealand laboratories.

A7.4.2 Extent of Non-Destructive Examination

In addition to visual inspection, four non-destructive examination methods are provided for by Part 1:-

(i) radiographic examination;

(ii) ultrasonic examination;

(iii) magnetic particle examination;

(iv) liquid penetrant examination.

Radiographic and ultrasonic examination are used to detect internal discontinuities; magnetic particle examination is used to detect surface and near surface discontinuities; and liquid examination testing is used to detect discontinuities open to the surface.

Guidance on the extent of routine testing recommended for each weld category is given in Table 7.4 of the Standard; more detailed discussion and suggestions on recommended levels of non-destructive examination are given in section A0 of this commentary. The use of each of these methods are discussed in section A6.2, A6.3 and A6.4.

Attention is drawn to note 7 of Table 7.4 recommending that consideration be given to examining welds for transverse weld metal cracking. As indicated in section A5.3.4 of this commentary, transverse weld metal cracking can be subsurface or surface breaking with detection using conventional radiographic and ultrasonic techniques being difficult and unreliable. To detect such cracks ultrasonically, it is necessary to remove the weld reinforcement to provide a flat surface for probe engagement and allow the ultrasonic beam to reflect from these imperfections laying transverse to the direction of welding.

Cold cracking (also known as delayed cracking) typically commences within 24 to 48 hours of the completion of welding, but may occur many days after the weld has been completed. The minimum time delay required prior to final non-destructive examination being carried out after completion of welding should therefore be given appropriate consideration (Reference 11).

Welds designed to NZS 3404 should be inspected in accordance with Appendix D of that Standard instead of Table 7.4 of AS/NZS 1554.1. Because of the seismic loadings New Zealand structures experience, Appendix D of NZS 3404.1 recommends a higher level of inspection (and provides more extensive guidance notes) than that shown in Table 7.4.

Part 1 requires that the drawings and/or contract documents clearly indicate what methods of non-destructive examination are to be used and what extent of testing is to be carried out. This is to enable the fabricator to be aware of the amount of testing involved, thus assess likely delays and additional costs in fabrication to enable the examinations to be carried out, and similarly assess any access requirements for the inspector. It is therefore recommended that in specifying the extent of testing that the percentage of testing be clarified as a weld length percentage or a number of welds percentage (note item 's' in Appendix D of Part 1 Matters for *Resolution*).

Where routine testing reveals imperfections requiring further consideration in accordance with section 6 of AS/NZS 1554.1, the extent of further NDE required will need to be determined in accordance with Clause 6.7 of AS/NZS 1554.1.

Clause 7.3 of Part 1 requires the inspector to "inspect the set-up of the work and ensure that the welds are in accordance with the drawings". This type of visual inspection is best termed "visual scanning" which also involves making "a careful and systematic check to ensure that no welds called for in the drawings are omitted".

Determination of whether "the work is performed in accordance with the provisions of this Standard" requires close visual inspection to which section 6 and Table 7.4 of Part 1 refer.

Where the level of inspection required is less than 100%, a programme of testing should be drawn up (preferably by the principal to the approval of the design engineer). This programme should involve full testing of the first major component fabricated or 5% of welds, as appropriate, in order to pick up and be able to correct the cause of any major defects on commencement of welding. It should then involve a progressive reduction in frequency of testing on the basis of achieving compliance with each test. If non-compliance results from a test, return should be made to consecutive testing of the next 5% of welds or the major component as appropriate.

Appendix B Brittle Fracture

Appendix B of Part 1 requires the designer to specify steel type based on the lowest metal temperature likely to be encountered during fabrication and erection, testing, or in service. The lower of this temperature and the LODMAT temperature must be used for the design.

The Appendix is based on statistical data available on the notch toughness characteristics (both Charpy and CTOD) of steels originally manufactured in Australia (References 17, 18, 19, 20, 21 and section C10 of AS 4100 Supplement 1). Table B1 was updated by Amendment 1 in 1998 after the production of additional data (Reference 22 compares current Australian steels with those steels on which the original table was based) and now includes a reference to steels manufactured in New Zealand. Caution is therefore required if the fabricator is using imported steels, and guarantees should be sought from the supplier to verify that the steel used will meet the requirements of Table B1 and this Appendix, or, conformance established by conducting a suitable fracture toughness assessment as detailed below.

General references dealing with the problem of brittle fracture should be consulted as the need arises.

For service temperatures, steel types, thicknesses outside of the scope of Table B1 and other non-complying conditions, it is necessary for the steel to tested and compliance established in accordance with clause B4.3.4.

Alternatively, or for special critical applications, it may be necessary to invoke clause B5 and arrange for a fracture mechanics assessment of the relevant members and joints to identify the minimum parent metal, heat affected zone and weld metal property requirements, and defect tolerances. This assessment would normally be conducted by a fracture mechanics specialist. It must be carried out using a recognised methodology such as that detailed in the British Standard BS 7910 or WTIA Technical Note 10. It is the responsibility of the designer and fracture mechanics assessor to consider all factors and situations that may affect the integrity of the structure. Items to be considered will include but not be limited to:

1. Fracture toughness assessment of the steel grade used is required at or below the design temperature. The designer is strongly advised to consult the steel supplier or manufacturer in selecting a suitable steel grade. Such an assessment should allow for any material anisotropy (variation in properties in different directions relative to the rolling direction, or with position), and the effect of section thickness on the toughness and fracture mode.
2. In some cases conventional Charpy impact properties may be converted to fracture toughness values but they are very conservative because of their high degree of uncertainty. In addition, the thickness effect mentioned above may allow a thin section to tear in a tough ductile manner but a thick section of the same material to fracture in a low toughness brittle manner. The disadvantage of using these conversions can be a reduction of the allowable stress and thus thicker materials requirements, the cost of which can greatly exceed the cost of carrying out the required fracture toughness tests. In general, tests must be carried out for at least the actual maximum section thickness and lowest temperature to be used, to achieve the minimum applicable toughness. The effects of any impact loadings may also need to be considered.
3. Where such an assessment is to include welds and weld defects, it is necessary to conduct a similar fracture assessment on the weld metal and its heat affected zone, including determining the fracture toughness of the weld metal and HAZ, and to qualify the welding procedure accordingly.
4. The assessment will define the maximum allowable size of imperfections that will not be detrimental to the performance of the structure in critical welds. It will therefore be based on either workmanship imperfection limits detailed in section 6 of Part 1, or the maximum size of imperfection that can reasonably go undetected by NDE in the finished joint or structure, whichever is the larger. Joints that cannot be fully NDE inspected should be avoided.

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This requirement differs from the fracture assessment of clause 6.7 of Part 1 in which the actual size of the detected defect is used to assess its affect on the integrity of the structure.

5. The designer should specify inspection and testing requirements covering the base material and welds, in consultation with the steel supplier or manufacturer as appropriate. All welds should at least be visually inspected, and all critical welds subjected to more detailed NDE inspection.

Appendix C Typical Forms For Welding Procedures

The format of the welding procedure documents shown in Appendix C of Part 1 were revised and reoriented to portrait mode in the 2000 edition of Part 1 to reflect the changes introduced in section 4. They contain all the information necessary to adequately record any weld procedure. Welding procedure documents need not necessarily follow the same format and may not necessarily require the same amount of information, although it is suggested that one standard format within any individual organisation is obviously desirable.

Some organisations may question the need for including the welder's name on the procedure documents. Again, this is not strictly necessary, although its inclusion will enable not only the qualification of the procedure, but also the qualification of the nominated welder for the procedure, thus obviating the need for separate qualification tests for both the welder and the procedure. A copy of the welding procedure specification should be given to the Welding Supervisor and the Welder and it should be prominently displayed adjacent to the welding in progress. A copy should also be made available to the inspector.

All procedure records should be retained by the fabricator once a procedure is qualified. A master-file of procedure records should be maintained by the fabricator and this master-file should also record the projects which have been successfully welded to Part 1 using the qualified procedures. For future work, re-qualification of the same procedure will not be required if a PQR for an already qualified procedure can be produced (see A4.2).

For guidance in the preparation and use of welding procedures, refer to WTIA Technical Note 19.

Appendix D Matters for Resolution

Appendix D of Part 1 is published as a reference list for the guidance of both principal and fabricator. This is a very important list which should be consulted for each welding application.

Whereas, in past editions of the Standard the phrase "by agreement" was used to denote items where some relaxation of the provisions of the Standard might be in order, or where no specific provisions are contained in the Standard, it is now the policy of the Standards Association of Australia to no longer have contractual matters in Standards published by the Association, but rather to restrict the Standards to technical specifications alone.

Where practicable, the matters in Appendix D of Part 1 are items which the principal and the fabricator should resolve before the contract is let, so that they form part of the contract documents. Other matters listed need resolution as the contract proceeds.

The background to each of the individual items may be found in this commentary in the comments on the relevant clause.

Appendix E Weld Joint and Process Identification

Appendix E of Part 1 explains the weld preparation identification coding used in the tables of prequalified weld preparations (Tables E1 - E4). These tables were moved from section 4 to Appendix E in the 2000 edition for the sake of clarity and navigation from section to section within the document.

The coding system used is similar to the American Welding Society system used in their structural welding code - AWS D1.1, thus allowing comparison of provisions, if desired. The identification system can be used if desired on shop detail drawings and welding procedure sheets.

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SECTION B: PART 2 – STUD WELDING (STEEL STUDS TO STEEL)

B0 Introduction

B0.1 General

Stud welding is "the attachment of a stud, or other suitably shaped part, to a metal surface by the production of a weld over the whole of the end area of the stud".

The two basic methods of stud welding of interest are Arc Stud Welding and Capacitor Discharge (CD) Stud Welding. Other stud welding methods involve friction welding and the attachment of studs with fillet welds using conventional open-arc welding processes.

CD Stud Welding is used for welding relatively small size studs in the range 2 to 8mm in diameter onto thin steel sheet and light steel sections and hence finds little use in structural steel welding. The method uses a low voltage electrostatic storage system as a power source in which the welding energy is stored at low voltage in capacitors of high capacitance. Depending on the method of arc initiation, short welding times prevent heat build-up and permit welding of steel studs to very thin sections without distortion, discolouration, or burn-through.

Arc Stud Welding was defined in the 1980 edition of Part 2 as "the attachment of a stud to a work-piece by the production of a weld over the whole of the stud base. The process is usually automatically controlled, wherein the heat for the process is obtained from an electric arc drawn between the stud base and the workpiece. Stud welding (as it is generally referred to herein) is an integral part of the welding of structural steel, and Part 2 applies particularly to the use of this method in structural and engineering applications.

B0.2 Stud Welding Equipment and Process

B0.2.1 Power Sources and Controls

Stud welding equipment consists of an integral high capacity DC power source and solid state controller module and a stud welding gun, together with the associated interconnecting cables.

The general characteristics desired in a power source for stud welding are:-

(i) high terminal voltage;

(ii) drooping power characteristics;

(iii) rapid current rise time;

(iv) high current output for a relatively short period - welding cycle times range from 0.1 - 1.5s at welding currents of 250-3000 A.

These operating characteristics usually mean that special welding power sources are required since conventional arc welding power sources are not usually designed for the high currents required. However, for small to medium stud sizes, they may be connected in parallel.

The control unit for arc duration, consists basically of a contactor suitable for interrupting the welding current and a timer with associated electrical components.

B0.2.2 Stud Welding Guns

There are two basic types of stud guns: portable and fixed. The portable or hand-held stud gun, which can be used for the entire stud size range, consists of a body, a mechanism to lift and plunge the stud, a stud holder or chuck, an adjustable ferrule holder and cables. After loading the gun with a stud and a ferrule, the entire welding cycle is initiated by a trigger on the gun.

The fixed production stud gun usually forms the head of a pedestal welding machine and is pneumatically operated and electrically controlled. The workpiece is positioned under the gun and automatic stud and ferrule feed may be incorporated.

B0.2.3 Connecting Cables

Total cable length and size is an important consideration since line losses may result in a reduction in the available power for arc stud welding at the gun, leading to unsatisfactory welds.

Figure B0.2.3 (Ref AWS C5.4) illustrates the influence of cable length and size on welding current at the gun from a DC generator power source. It is therefore essential that stud application procedure qualification (see section B3, B4) be done using equipment and cable lengths corresponding to that to be used on the job.

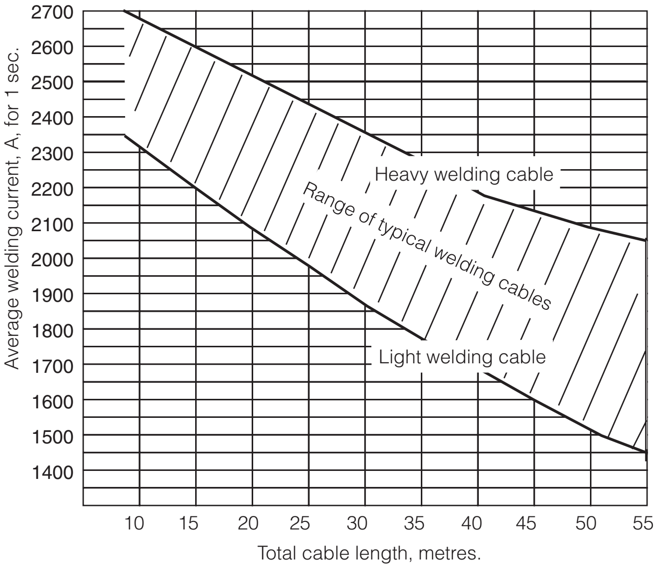

Figure B0.2.3 Effect of Cable Length and Size on Stud Welding Current

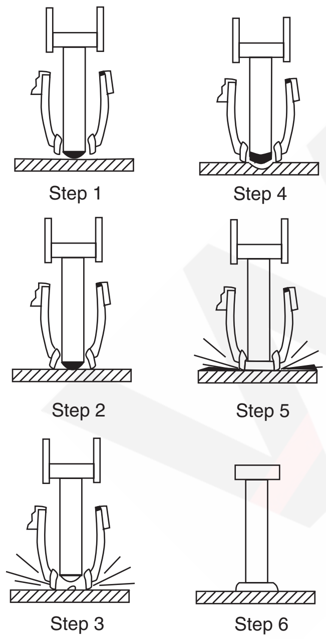

Figure B0.2.4 Stages of the Arc Stud Welding Process

Note that modern computer controlled stud welding equipment can automatically compensate for current losses due to varying resistance in the power cable and the above assessment is not required.

B0.2.4 Welding Sequence

The welding sequence in conventional arc stud welding is shown in Figure B0.2.4. In step 1, the stud is located on the spot to which it is to be welded. Applied pressure to the gun (Step 2) seats the ferrule firmly against the work. The trigger is then squeezed initiating the weld cycle. The solenoid energises and the lifting mechanism in the stud gun lifts the stud against a spring (step 3), thereby developing and drawing an arc between the stud base and the workpiece. In step 4, the arc melts the stud base and a local area of metal under the stud. When the cycle is automatically completed, the solenoid de-energises and the spring forces the stud onto the workpiece (step 5). Note that modern computer controlled arc stud welding equipment uses different technology.

Most of the molten metal is displaced from the weld zone and forms a fillet under the restraining effect of the ferrule. When the weld has cooled, the ferrule is knocked off to complete the weld (step 6).

B0.3 Rationale of Part 2

The stud welding process is capable of repeatedly producing good quality welds, but the integrity of the welds depends greatly on the correct qualification of consumables and procedures, workmanship and inspection of finished welds. Originally developed using section 7 of AWS D1.1 as a guide, Part 2 is a performance-type specification designed to ensure welds of an acceptable quality.

Part 2 details the requirements for welding steel studs to steel members and provides the mechanical requirements, workmanship and quality control necessary to assure that welded studs will perform the intended service. Part 2 requires the use of stud bases qualified by the stud manufacturer.

Providing the requirements of Part 2 are observed, the stud welding process can be applied with confidence to a wide range of structural and general engineering applications.

B0.4 Changes to Part 2

The 2003 edition being the first joint edition with New Zealand, has introduced some significant changes from the 1993 edition. In summary these were:

(i) New definitions added in accordance with the changes.
(ii) Reference to the Australian AS 3597 steels has been added.
(iii) Safety requirements have been enhanced to assess and manage the risks associated with Stud Welding activities.
(iv) Allowance is made for the use of wet-weather capable stud welding machines with procedures to be qualified in accordance with Section 3 and all studs so welded in production Ring Tested.
(v) Allowance is made for the use of a machine that records all parameters giving a higher level of quality assurance than is possible using conventional stud-welding machines.
(vi) Welding through paints and primers is permitted, but subject to approval by the Principal with all production studs to be Ring Tested.
(vii) Qualification requirements for stud welding operators have been enhanced.

B1 Scope and General

As the clause makes clear, Part 2 only applies to:-

(i) steel studs which are welded to
(ii) steel parent material, using the
(iii) stud welding process

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Stud welding through galvanised steel sheeting, for example in composite beam/composite floor systems, is included within the provisions of Part 2.

The basic principles of Part 2 is that all stud welds shall:

- only use studs or shear connectors with qualified stud bases;
- be made in accordance with a qualified stud-welding procedure;
- be made by a welder suitably qualified to carry out such a procedure; and
- comply with all the appropriate requirements of the Standard.

As indicated in section B0, Part 2 encompasses both conventional stud welding and capacitor discharge welding. Alternative welding processes may be permitted under clauses 1.2 and 5.2.3 of Part 2.

Friction welding was specifically excluded in the 1980 edition of Part 2 but is not mentioned in the 1993 or 2003 editions. In these editions however, friction welding (like other innovative or novel processes) is only excluded in the sense that no special provisions for its execution are included within Part 2. As indicated in clause 1.2 of Part 2, most of the clauses of Part 2 could also be applied to this process, and any additional provisions should be agreed between principal and fabricator at the time of signing the contract. The use of friction welding at present in Australia and New Zealand is limited.

A wide variety of shapes of steel studs are available to suit a number of applications, including:-

(i) shear connectors for composite beams in building and bridges;

(ii) concrete anchors; examples include:
  - supports for elevator shafts;
  - expansion joints;
  - stair forms;
  - attachment of curtain walls;

(iii) fasteners for attachment of light fixings to main steel members; examples include:
  - door framing;
  - attachment of sprinkler systems, duct work;
  - supports for ceilings, racks, light fixtures;
  - attachment of insulation;

(iv) general engineering; examples include:
  - pins and studs for mounting of bearings, guides.

Studs made of material other than steel (such as aluminium, copper, stainless steel) are excluded from the scope of Part 2, although the use of novel materials that give equivalent results to those listed in the Standard are not specifically excluded (clause 1.2 of Part 2).

Being a Standard for structural applications, stud welding for pressure vessel applications is specifically excluded from the scope of Part 2, even though the welding of studs to pressure vessels is not directly dealt with in AS 3992.

B1.4 Definitions

Most definitions remain unchanged from previous editions however three new definitions were added in 2003. They are self explanatory.

The Ring Test is a common industry test that utilises the sound generated to indicate a pass or fail.

The definition of *wet weather capable* was incorporated primarily for safety reasons and as noted below in section B1.6, reference is made to the latest edition of AS 1674.2 where restrictions are placed on the open circuit voltage that the stud welding operator may be exposed to under wet or damp conditions.

B1.6 Safety Precautions

In addition to updating the referenced Standards contained in Clause 1.6.1 and 1.6.2, the 2003 edition of Part 2, like other Parts of the AS/NZS 1554 series, has introduced the requirement to consider and manage other hazards associated with welding. This requirement is in keeping with statutory obligations faced by fabricators under Occupational Health, Safety and Rehabilitation legislation. Given the changes in sections 3 and 5 of Part 2, the need to control and manage the dispersal of emitted fume is highlighted.

As indicated in section B1.4 above, the reader's attention is also drawn to recent changes to AS 1674.2 particularly when considering welding in wet or damp conditions.

B2 Materials of Construction

B2.1 General Requirements for Studs

B2.1.1 Stud Design

Most studs are of circular cross-section ranging in diameter from 6.4mm to 31.8mm (¼" to 1¼"), although some studs of rectangular cross-section are available. Sizes of studs remain essentially Imperial since they are either imported from America or manufactured in Australia on imported equipment. Hence, all the dimensions in Figure 2.1 of Part 2 are soft metric conversions of Imperial dimensions. Rectangular studs can be difficult to stud weld satisfactorily, and the American Welding Society (Reference 6) does not recommend stud welding when the width of the stud is more than five times its thickness. During stud welding, a portion of the stud is burnt-off, the amount of burn-off depending upon the diameter of the stud. The finished length after welding is consequently shorter than the original length of the stud. In the 1980 edition of Part 2, the finished length of the stud after welding was specified (with a tolerance), however, this requirement was deleted from the 1993 edition of the Standard and the more realistic manufactured length of the stud specified instead. Melt-off requirements are now covered by section 5.2 and 5.4 of Part 2. Whilst this is consistent with the American approach through AWS D1.1, ISO through ISO 13918 still specifies the finished length of the stud after welding.

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B2.1.2 Ferrule

An individual ceramic ferrule is required for each stud. The ferrule is placed over the stud and is held in position by a grip or holder suitable for the particular application. The ferrule performs several important functions during the welding cycle (Reference 6, AWS C5.4):

(i) it concentrates the heat of the arc in the welding area during the weld;

(ii) it reduces oxidation of the molten metal during welding by restricting passage of air to the weld area;

(iii) it confines the molten metal to the weld area;

(iv) it prevents burning of surrounding material and possible contamination of the weld metal;

(v) it protects the eyes of the operator from the arc, thereby eliminating the need of a welding mask. Safety glasses are recommended;

(vi) when welding through galvanised decking, it permits the zinc fumes to escape while effectively confining the molten metal to the weld area. Ferrules for through deck and clean beam stud welding are not interchangeable.

Generally speaking, the standard ferrule is cylindrical in shape and is flat across the bottom for welding to flat surfaces. The base of the ferrule is serrated to form vents, and its internal shape moulds the molten metal around the base of the stud to form a weld fillet. Special types of ferrules may be used for particular applications, such as welding at angles, welding to contoured surfaces etc. For such applications, the ferrule is designed so that its bottom face matches the required contour. A special ferrule is also required for welding through steel sheet (see section B5.5 of this commentary).

The weld fillet formed around the base of the stud is controlled dimensionally by the design of the ferrule. The diameter of the fillet is generally larger than the diameter of the stud, (see section B5.4 of this commentary) therefore, some consideration of the fillet diameter and height may be required in the design of mating parts.

B2.1.3 Flux

The stud base to be welded is either recessed to contain a quantity of flux or, alternatively, the flux may be affixed to the stud base. The flux acts as an arc stabiliser and deoxidising agent, and together with the shielding action of the ferrule, protects the molten weld metal from oxidation during welding and solidification.

B2.1.4 Stud Bases

Only studs with qualified stud bases can be used for stud welding. In most cases, the stud manufacturer is responsible for this work. - refer to Appendix C in Part 2.

B2.1.5 Manufacture

The method of manufacture of the finished stud can include heading, rolling or machining. The stud is to be free from various discontinuities and defects. However, unlike its predecessor, the 1993 and 2003 versions of Part 2 notes a slight relaxation in the requirement for minor defects in the stud head subsequent to manufacture. Stud and ferrule descriptions and statements of compliance must be forwarded by the fabricator when requested by either the principal or inspecting authority.

B2.2 Stud Material

B2.2.1 Manufacture

Steel from which studs are usually made is a low-carbon steel with approximate maxima of 0.23% carbon and 0.60% manganese.

Steel to AS 1443 Grades 1010 through 1020 are Australian equivalents of stud steels specified in clause 7.2.6 of AWS D1.1 (ASTM A108, grades 1010 through 1020), and have chemical compositions within the above limits. Either semi-killed (e.g. S1010, S1012 etc) or fully-killed steel (e.g. K1010, K1012 etc) may be used. Note that the deoxidation practice is now often unspecified in Australia given that variants on fully killed steels only are available (e.g. aluminium killed, silicon killed etc). As such, since 1994 the AS 1443 grades are often ordered 'unspecified' e.g. U1010, U1012 etc (the prefix 'U' is optional).

B2.2.2 Mechanical Properties

The mechanical properties of studs are determined by measuring its tensile properties in accordance with AS 1391. The tensile test requirements are similar to those in clause 7.3.1 of AWS D1.1, except for the elongation requirements which are measured in accordance with AS 1391 in the case of Part 2. The gauge length varies with the cross-sectional area of the stud in accordance with AS 1391. A further differential between Part 2 and AWS D1.1 is that the former has two strength categories whilst the latter also includes a third high strength (550MPa) stud.

The minimum tensile strength of studs used as shear connectors is required to be 410 MPa in AS 2327.1, so the minimum specified in this clause (410 MPa) is in line with the requirements for composite beams. It is not necessary for this clause to specify a minimum yield stress for non-shear connectors. The mechanical properties appear in what is essentially a welding standard because, at present, no Australian Standard exists which deals with the required mechanical properties of studs.

B2.2.3 Certification

The stud manufacturer should be in position to supply test certificates which state that the studs in a given batch comply with the requirements of this clause provided that the fabricator has requested such certificates when purchasing the studs.

B2.3 Parent Material

The steels specified in this clause are essentially the same steels specified in clause 2.1 of Part 1 of AS/NZS 1554, and represent the most common steels used in the structures and applications discussed in section B1 of this commentary. These steels have prequalified status.

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Steels to Australian Standards to which studs could also be welded in terms of Part 2 include:-

AS 1074 Steel tubes and tubulars for ordinary service

AS 1442 Carbon steels and carbon-manganese steels: Hot-rolled bars and semifinished products

AS 1443 Carbon steels and carbon-manganese steels: Cold-finished bars

This is not an exhaustive list of steels to which studs could be welded using Part 2 and which can be included in terms of Part 2 under clause 1.2. Such steels or similar steels to other Standards require the establishment of a satisfactory welding procedure in accordance with section 3 of Part 2.

Apart from the common structural steel material Standards, Part 2 permits the use of parent material with a specified minimum yield strength not exceeding 800 MPa (450 MPa in the 1980 edition). This is due to the growing use of applying welded studs to the AS 3597 series quenched and tempered structural steels.

B3 Stud Application Qualification

B3.1 General

It is essential that the conditions used for qualifying the welding procedure correspond with those expected to be encountered on the job. Like other parts of the AS/NZS 1554 Standard series, Part 2 also grants concessions through pre-qualification thus only requiring the limited pre-production testing of section 4 and test requirements of section 6 of Part 2 where studs are welded within the limits of the stud manufacturer's base qualification tests (Appendix C) in the flat position (i.e. the conventional arc welding 1G position). The word 'horizontal' here refers to the test plate being horizontal to the ground and not the weld position.

The tolerance for flat position is defined as 0° to 15° slope on the surface to which the stud is applied. It should also be noted that reference to Appendix A in the first paragraph of the clause in the 1993 edition should be to Appendix C. This was corrected in the 2003 edition.

In all other cases, (including stud welding in the 2G, 3G and 4G positions) the stud application must be initially qualified by more extensive tests (as noted in the balance portion of section 3.1 of Part 2) than those required by section 4.1 of Part 2. Such tests do not have to be done by the fabricator, but the fabricator is responsible to ensure that they are carried out.

Section 3 of Part 2 is a significant change to section 3 in its 1980 predecessor. The primary aim of this section is to establish a clear distinction between stud base qualification (clause 2.1.4 of Part 2) and stud application qualification for welding under shop or field conditions (e.g. including if sheet metal is in place). The 2003 edition also mandates the requirement that testing be undertaken on materials representative of that to be used in the fabricated structure, with particular emphasis being noted in relation to the use of coated materials and welding in wet or damp conditions. All stud bases must be qualified either by pre-qualification (Appendix C) or testing as noted in this section.

Specific comments regarding the welding through uncoated and galvanised sheet steels can be found in clause B5.5 of this commentary.

B3.2 Preparation of Test Specimens

This clause considers the preparation of test specimens for non-prequalified test specimens as noted in clause 3.1 of Part 2. The test plate grades considered should match the actual base metal type. Ten specimens are to be welded consecutively using recommended procedures and optimum weld settings for each final stud configuration i.e. each stud diameter, weld position, and surface geometry requires its own set of welding parameters and set of ten test pieces. All parameters must be recorded.

B3.3 Testing

B3.3.1 General

Although Part 2 is not explicit about testing other than by bending (clause 3.3.2) or tension (clause 3.3.3), good practice dictates that the initial test of welded studs for qualification of the procedure or operation should be a visual examination to assess that a full 360° fillet is well formed. An inconsistent flash around the base of the stud may indicate that the welding parameters should be corrected and further test welds done before testing (see Figure B5.6.1).

Studs need only be tested using one of the nominated methods unless contractually required otherwise. This will depend on the final intended application. Studs subjected to a tension load in service should be tension tested appropriately.

Normally, the use of prequalified studs welded in the flat position on clean steel requires only two test studs (as noted in clause 4.1 of Part 2). In all other cases including welding out of position, through sheet steel etc., ten tests are required as noted below.

When welding in wet or damp conditions, the requirement to delay commencement of testing for at least 24 hours has been introduced to detect the possible onset of delayed cold cracking arising from hydrogen embrittlement of the weld, particularly when stud welding onto higher strength and quenched and tempered steels.

B3.3.2 Bend Test

This test requires that, after being allowed to cool (nominally to a temperature less than 60°C as noted in the 1992 edition of this commentary) each of the ten test studs welded shall be tested by bending to an angle of 90° from their original axis. No specific method is noted though bending is usually undertaken by striking with a hammer or may be by the alternative method of slow bending with a special tool. Whilst the simple hammer blow test is a more severe bend test, it should not be used when ambient temperature falls below 10°C (see section 4.1 of Part 2).

In the event of failure during the bend test (by fracture occurring in the weld or its heat affected zone) the procedure must be modified and ten more studs welded and tested. The changes made to the welding procedure should be recorded.

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If failure occurs in any of these studs, further test welds should then be performed until a satisfactory procedure is established. Ten consecutive studs are required to be welded and all must pass the bend test before any production welds are done.

Fractures outside of the weld (i.e. in the parent plate or in the stud shank) are not cause for rejection. If during bend testing repeated failures occur in the stud shank away from the weld, it is advisable to refer the incident to the stud manufacturer to ascertain the cause of the failure before any further welding is carried out.

B3.3.3 Tension Test

The tension test configuration is based on whether the stud is threaded or not. Threaded studs can be tension tested by torque control methods and non-threaded studs are tested by a tension test machine. Both types of tests are to specimen destruction and again failure must not occur in the weld for qualification.

In the case of threaded studs, depending on stud geometry and strength, failure is expected to occur via either the thread stripping or tensile failure (especially for reduced section studs). The purpose of the torque loading given in Table 3.1 is to primarily establish the integrity of the testing system (i.e. soundness of welds and structure etc) before loading to failure. Measurement of the torque load at failure is not required as the sole weld acceptance criteria are that the stud should not fail in the weld.

Refer to section B6.2 of this commentary for further information on the tension test for threaded studs.

B3.4 Test Data

All material supply and test data used in section 3 stud application qualification tests are to be recorded and maintained. Copies of these records must be made available to the principal or inspecting authority when requested.

B4 Procedural Control

B4.1 Preproduction Testing

The 2003 edition of Part 2 introduced separate requirements for stud welding machines capable of recording all welding parameters. The requirements of clause 4.1.1 are similar to those of clause 4.1.2 except that allowance is made for the high degree of reproducibility now available to the stud welding operator through the use of such machines.

B4.1.2 For a stud Welding Machine Which Does Not Record Weld Cycle Parameters

B4.1.2.1 Daily Tests

Assuming that the stud complies with the stud application qualification provisions of section 3, clause 4.1.2.1 requires that at the start of each day or shift, or where changes are made to the weld procedure (e.g. in weld set-up, size or type of stud etc.), testing is to be performed on the first two studs to be welded. Alternatively, the two test studs may be welded onto another member or test coupon of similar material (mechanical and chemical properties), thickness (±25%) and surface quality to the production member, and in the same welding position as the production stud i.e. flat (1G position) vertical† (2G or 3G positions) or overhead (4G position).

The two test studs are then visually examined for the presence of a full (i.e. 360°) flash. Following visual examination, and after being allowed to cool to ambient temperature (nominally a temperature less than 60°C as noted in the 1992 edition of this commentary) the test studs are then tested by bending to an angle of 30° from their original axis by striking with a hammer or by using a suitable hollow device to lessen strain rate by manual or mechanical means. The clause adopts a similar approach to clause 7.6.6.1 of AWS D1.1 since it was considered impractical to insist on a controlled strain rate test. Whilst the simple hammer blow test is a more severe bend test, it should not be used where the ambient temperature is at or below 10°C.

For threaded studs the tension test prescribed in Clause 3.3.3.1 of Part 2 should be substituted for the above bend test.

B4.1.2.2 Retests

In the event of failure during the tests above (by fracture occurring in the weld or its heat affected zone) the procedure must be modified and two more studs welded and tested. The changes made to the welding procedure should be recorded.

If failure occurs on either of these second studs, additional test welds should then be performed until a satisfactory procedure is established. Two consecutive studs are then required to be welded and must pass the above test before beginning or continuing with any production welds.

B4.2 Production Welding

As noted in clauses 4.1.1 and 4.1.2 of Part 2 and clause B4.1.2 above, any change in welding set-up shall require a re-qualification test as described in clause 4.1 of Part 2.

B4.3 Stud-Welding Operator Qualification

Significant changes were made to clause 4.3 in the 2003 edition. The fundamental approach is similar to welder qualification requirements in other parts of the AS/NZS 1554 series in that the stud-welding operator is required to be suitably qualified.

Clause 4.3.2 introduces the requirement that the operator have sufficient technical knowledge to operate their machines and understand the significance and consequence of any adjustments to parameters they make. In the event that an operator is unable meet the requirements of clause 4.3.2, they are permitted to continue stud-welding under the direct supervision of a qualified stud-welding operator provided that they can successfully weld the pre-production tests required in clause 4.3.3 for all operators.

† For stud welding, the term 'vertical' is used to describe a weld which in conventional terms may also be thought of as horizontal i.e. in both cases, the stud is parallel (horizontal) to the ground.

A successful preproduction test (clause 4.3.3) as nominated in clauses 4.1 and 4.2 of Part 2 also form part of the qualification requirements of the stud-welding operator. To qualify a new operator (even where a qualified welding procedure is used) the provisions of clause 4.1 applies i.e. the new operator must also pass the preproduction test.

Note: *For each new operator and procedure qualification test, and preproduction test, it is strongly recommended that all test data be recorded on a Stud Welding Procedure Sheet (e.g. Figure B4.3 page 65). Computer controlled stud welding equipment can provide a printed record of each stud welding cycle.*

B5 Production Technique and Workmanship

B5.0 General

Section 5 of Part 2 considers actual production welding and assumes the pre-qualification criteria in sections 3 and 4 are satisfied. As explained in clause 4.3 the "simultaneous qualification of the welding procedure and welding operator" is permitted in Part 2.

B5.1 Preparation Before Welding

B5.1.1 Studs

The storage of studs should be such that at the time of welding, the studs are free of any surface contamination (rust, oil, dirt) which could adversely affect the welding operation and weld quality.

B5.1.2 Stud Base

Particular attention should be given to maintaining the stud base in the original condition as supplied by the stud manufacturer, since the qualification of the stud base is only valid whilst such conditions are maintained.

B5.1.3 Ferrules

Wet or damp ferrules can cause weld quality problems aside from any safety concerns that may arise with molten weld metal coming into contact with moisture.

When used in wet weather capable stud-welding machines, ferrules must be kept dry until placed in position and the weld cycle commenced immediately. Should a delay occur between the placement of the ferrule and preparation for initiation of the weld cycle, the wet or damp ferrule should be replaced with a dry ferrule due to the ferrule's potential for rapid absorption of moisture and resultant safety and weld quality risks.

B5.1.4 Parent Material

Prior to welding, surface areas to which studs are to be welded must be clean and free of such foreign matter that may adversely effect the welding operation and weld quality. For most stud welders they must also be dry. It is important that during production welding, the surface condition is the same as that during qualification of the welding procedure (sections 3 and 4 of Part 2).

Oil, grease, indelible markings or similar contaminants should be removed using acetone or other such solvents. The use of chlorinated hydrocarbons should be avoided since potentially toxic gases may be generated during subsequent welding operations. Other surface coatings (e.g. paint, heavy oxide) must be removed by mechanical means (wire brushing, grinding or linishing, grit blasting, and end milling) and/or chemical methods.

It is not always practical to locally remove all of the paint from the surface upon which studs are to be welded. As early trials (unpublished) by BlueScope Steel Limited showed that it was possible to arc stud weld through thin coats of certain paint systems, research work was initiated within the Co-operative Research Centre for Welded Structures (CRC-WS) to quantify these findings. Whilst the CRC-WS work demonstrated that satisfactory arc stud welds can be made through thin coats of paint and weld-through primers (Reference 25), further research is required as it is known that arc stud welding is more sensitive to paint contamination than the typical wire based arc welding processes. It is therefore recommended that surfaces to receive welded studs are not pre-painted, however, if weldable primers and paints are intended to be used, then trials should be undertaken in accordance with section 3 using the equipment to be used in the contract, to determine if the paint or primer is suitable to receive arc welded studs.

Other paints (e.g. red lead) may cause unsatisfactory welds. Initial electrical contact must be made between the stud and the work to draw a welding arc. Most control units provide a pilot arc to facilitate this, but often a centre punch or other mechanical means must be used to penetrate the coating. Once contact is made, the flux, pilot arc and welding arc assure satisfactory welds.

When a suitable welding procedure through paint or weldable primer has been established in accordance with section 3, the 2003 edition of Part 2 requires the principal to give due consideration to the potential for high failure rate of studs so welded and control and dispersal of emitted fume, before allowing production welding through painted surfaces to commence. All studs welded through painted or primed surfaces (including painted steel sheeting if used) must be Ring Tested.

Using special techniques, the welding of studs to members through coated or plain steel sheeting is permitted (see section B5.5).

B5.2 Welding

B5.2.1 General

Welding current and weld time are the two most important determinants of arc stud weld quality. These two factors determine the energy input into the weld and, hence, the degree of melting of the stud base during the weld cycle.

During procedure qualification and production welding of studs to steel members, the arrangement of the automatically timed stud welding equipment should be in accordance with the manufacturer's recommendations.

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Stud welding should be performed with a suitable DC power source. Welding current and time varies with the size of the stud and Figure B5.2.1 shows approximate weldability ranges corresponding to each stud size (References 6, 23, AWS C5.4).

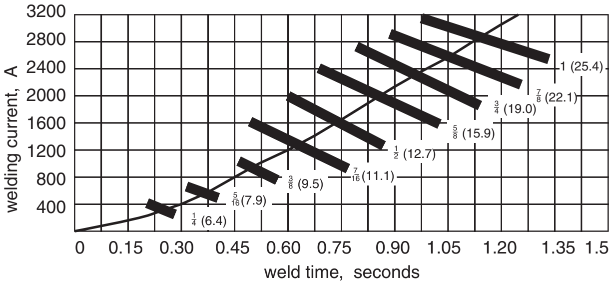

Figure B5.2.1 Current-Time Ranges for Mild Steel Studs

Because of the short arc times, it is essential that properly set, automatically timed equipment is used. The American Welding Society in its AWS D1.1 recommends adjusting the timing device on the control unit and power source to the approximate settings given in Table B5.2.1 from AWS C5.4.

With the power source timing device on the control unit and the stud gun lift mechanism adjusted to suit the size of stud to be welded (using guidance from the manufacturer and through procedure qualification tests) the stud is inserted into the stud gun, the ferrule is then placed over the stud base and seated against the ferrule holder. The stud should extend beyond the ferrule by a length at least equal to the maximum length the stud shortens during welding (refer to the manufacturer's recommendations). The welding gun should be held perpendicular to the member surface and force applied until the ferrule is firmly seated against the member. The trigger of the stud gun can then be actuated and released. The stud gun should not be moved during the welding cycle, and in accordance with Clause 5.2.1 "shall be held in position without movement until the weld metal has solidified".

Another welding gun requirement is the interlocking of power demand when two or more welding guns are used with the same power source. Due to the high demand duty cycle, the interlocking of the welding guns must be such that only one gun can operate at a time (after an appropriate power source recovery period) unless the power source is specifically designed to cater for multiple stud guns firing simultaneously.

B5.2.2 Adverse Weather

Site welding should not be performed when the base metal temperature is below -20°C, since the quenching effect on the solidifying weld metal may induce weld and heat affected zone cracks. Undertaking stud welding in falling rain may be hazardous unless the equipment is specifically designed for safe, dependable stud welding in wet conditions. Where the base steel temperature is at or below 0°C, care must taken to ensure that any surface to be welded is dry and free of ice and snow. Note that under such circumstances additional production tests are required (1 stud in every 100 to be bent 15°) over and above the preproduction tests.

B5.2.3 Alternative Welding Processes

The 1980 edition of AS 1554.2 only allowed fillet welding for minor repairs of installed studs in which a full 360° flash was not obtained. However the 1993 and 2003 editions permits studs to be initially welded by conventional arc welding processes provided that prior approval has been given by the principal or inspection authority. Such a procedure would only occur where small numbers of studs may require welding and the employment of a stud welding specialist or contractor is too costly. Under such circumstances, welding must be carried out in accordance with AS/NZS 1554.1, AS/NZS 1554.4, or AS/NZS 1554.5 as appropriate.

B5.3 Stud Spacing

Studs are usually positioned by laying out and marking or centre-punching the parent material, or in special cases by the use of a template and centre-punching. Using the centre-punch method, the operator puts the point of the stud in the centre-punch mark and welds - an accuracy of ± 3mm should be readily obtained. Whilst the specific requirements of this clause were modified in the 2003 edition to accommodate New Zealand requirements, laying out without centre punching should also have no difficulty meeting the ± 20mm limit of the clause.

Application Standards may have different spacing requirements than those given in the clause. The requirements in the clause are intended to ensure efficient and satisfactory welding with sufficient clearance to allow correct welding procedure. AS 2327.1 has no minimum longitudinal spacing requirement but has a transverse spacing requirement sufficient to leave a clear distance between the heads of not less than 1.5 times the shank diameter of the stud. The Australian Bridge Design Code (Reference 1) has a minimum centre-to-centre spacing requirement of 75mm in any direction (compared with 65mm in this clause).

Both AS 2327.1 and Australian Bridge Design Code have a minimum edge distance requirement of 25mm compared to the 50mm of this clause (measured from edge of stud to edge of flange/plate).

B5.4 Finished Welds

Part of the material from the length reduction of the stud appears as flash in the form of a fillet around the stud base. This fillet is not to be confused with conventional fillet weld since it is formed in a different manner. When properly formed, the fillet indicates complete fusion over the full cross section of the stud base and suggests that the weld is free of defects.

The stud weld fillet may not be fused along its vertical leg - this lack of fusion is not considered detrimental to the stud weld quality.

The ferrule is required to be removed from the finished weld in order to allow visual inspection.

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Table B5.2.1 Typical welding conditions of arc stud welding of steel studs to steel). (Note 1).

Stud base diameter in	mm	Weld time (sec)	Welding Current Amps (Note 2)
1/4	6.4	0.17	425
5/16	7.9	0.25	500
3/8	9.5	0.33	550
7/16	11.1	0.42	675
1/2	12.7	0.50	800
5/8	15.9	0.63	1200
3/4	19.0	0.83	1400
7/8	22.1	1.0	1700
1	25.4	1.17	2000

Note: 1. Settings should be adjusted to suit job conditions
2. The current levels shown are actual welding currents and do not necessarily correspond to power source dial settings.

B5.5 Stud Welding Through Sheet Metal

Profiled steel sheeting is often used in composite beam construction in buildings and occasionally in bridges. The sheeting is laid on top of the steel beam and shear connectors are used to make a composite beam in which the steel beam acts compositely with a concrete slab poured onto the steel sheeting (Reference 5).

When profiled steel sheeting is used, the stud has a decided advantage as a shear connector. With other types of welded shear connectors, it is necessary to provide openings in the sheeting either to enable the sheeting to be fitted over shop welded shear connectors or to site weld a shear connector. Early practice was to provide slotted holes for stud shear connectors, but this has given way to a "weld-through" process in which the stud is positioned in a welding gun on the sheeting. The arc melts the sheeting, the stud end, and the parent material.

A stud base qualified under clause 2.1.4 requires a special qualification for this type of application if a special ferrule is used (discussed below).

Originally, the stud welding process was restricted to "black" or unpainted sheeting, or to galvanised sheeting with a zinc coating no heavier than 75g/m^2. Methods are, however, now available which enable stud attachment through galvanised sheeting with much heavier coating masses. The 1980 edition of Part 2 had a coating mass limit of 400 g/m^2 (rounded up from 380g/m^2). The weld-through technique requires a number of special conditions:- (Reference 6)

(i) a special ferrule must be used to allow for the rapid evacuation of zinc oxide vapour;

(ii) galvanising must have been carried out by an electrolytic or by a continuous dip process;

(iii) the top flange of the beam and underside of the sheeting must be free at the point of welding from dirt, paint, heavy rust, mill scale and in most cases water;

(iv) a special welding gun must be used;

(v) 3-phase power must be available on site;

(vi) no gap exists between the steel sheet and the parent material.

Pease and Preston (Reference 24) discuss the parameters which must be controlled in order to successfully stud weld through galvanised steel sheet. They make the following points:-

(i) Zinc oxide vapour in the welding environment causes weld defects, largely occurring as porosity caused by the entrapment of zinc oxide vapour in the solidifying molten metal.

(ii) Zinc oxide forms during welding and is entrapped in the weld area and deposited in the molten metal. This interferes with proper bonding of the metal and causes an unsound weld. The deposition of zinc oxide on the side walls of the stud prevents fusion of the weld fillet to the sides of the stud.

(iii) The low boiling point of zinc also produces pressure inside the ferrule. As a result, spatter and the ejection of metal from the ferrule leaves insufficient molten metal to effect a good bond between the stud and the base plate. Spatter directed towards the neck of the ferrule causes "hang-up" due to the inability of the stud to plunge.

Pease and Preston welded 19.0 mm diameter studs through 1 mm galvanised steel sheet (galvanised coating 380g/m^2) using standard techniques for welding studs to bare steel. They reported excessive porosity due to entrapped zinc vapour, and lack of fusion between the fillet and the stud.

They established that at least two of the requirements for successfully welding studs through galvanised decking with 380g/m2 coating were:-

(i) increased welding time;

(ii) increased venting through the ferrule.

Using a modified ferrule design, increased welding time and stud welding in accordance with AWS D1.1 produced stud welds which qualified under the terms of that Code.

Based on the Pease and Preston tests, the following comments are made relevant to the use of Part 2:

(i) A stud base qualification in terms of Part 2 should be carried out with the ferrule type to be used for welding through galvanised steel sheet.

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(ii) When welding is to be done through galvanised steel sheet, unless the welding time is increased, a satisfactory welding procedure is unlikely to be obtained.

In addition to the above, workmanship provisions are also critical. Specifically, it is of course extremely important that no moisture exists between the steel sheet and the steel member when stud welding through the sheet using conventional technology. There should be no air gap between the two components as any such gap causes the stud welding arc to have to bridge across the gap in the early part of the welding cycle.

Unfortunately, at the present time, no data is available as to the extent of gap which is tolerable, and research on this question is clearly needed. In the absence of data, Part 2 calls for the conservative approach of no gap.

Any stud application procedure qualified in accordance with section 3 and followed up the procedural control tests of section 4 is, by definition, satisfactory provided that these criteria regarding moisture and gap are met. The procedure must be established with a sample of the steel sheet placed between the stud and the parent material. A special ferrule may be required for arc stud welding through galvanised steel sheeting and the welding time may need to be increased.

B5.6 Workmanship

B5.6.1 General

After removal of the ferrule, the weld should be visually inspected. Figure B5.6.1 illustrates some defective welds on studs.

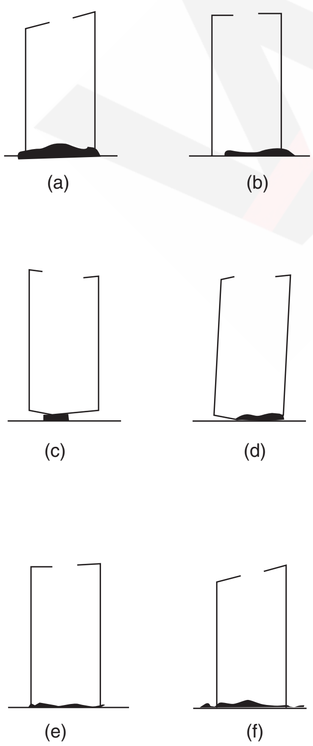

Figure B5.6.1 Acceptable and Defective Arc Stud Welds

Figure B5.6.1(a) indicates a satisfactory stud weld with a good weld fillet formation. In contrast, Figure B5.6.1(b) shows a stud weld in which the plunge was too short. Prior to welding, the stud should always project the proper length beyond the bottom of the ferrule (see B5.2.1). This type of defect may also be caused by arc blow. Figure B5.6.1(c) illustrates hang-up. This condition may be corrected by adjusting the gun to ensure completely free movement of the stud during lift and return. Arc length may also require adjustment. Figure B5.6.1(d) shows poor alignment, which may be avoided by positioning the stud gun perpendicular to the work to assure seating of the ferrule (see B5.2.1). Figures B5.6.1(e) and B5.6.1(f) show the results of low heat and high heat, respectively. In the first instance, the work leads and connections should be checked, and the power setting, the time setting or both, should be increased. It may also be necessary to adjust the arc length. Further guidance on the correction of stud welding problems can be obtained from ISO 14555.

Decreasing the power setting, the time cycle, or both, will ensure that the amount of heat is not too high.

Welded studs which do not comply with the full 360° weld flash are deemed unacceptable.

When stud failures are confined to the shank of studs or weld metal, the remaining materials may be removed and the work surface ground so that it is clean and flush before welding of a replacement stud. In areas subject to compression only, a new stud may be welded adjacent to each unacceptable area in lieu of repair of the original weld area (see clause 5.6.2.2).

Defective welds may be repaired by adding a fillet weld using an arc welding process in place of the missing weld fillet. Part 2 does not explicitly require that the combination of the stud weld and the fillet weld must ensure that a sound weld across the stud base is achieved. In some cases this condition may not be achieved. Defective welds which are repaired by fillet welding should therefore be tested in accordance with section 6 of Part 2.

Preheating may be required and welding with any suitable process shall be carried out in accordance with AS/NZS 1554.1, AS/NZS 1554.4 or AS/NZS 1554.5 as appropriate.

The minimum fillet weld size should conform to the requirements of Table 5.1 of Part 2. This condition ensures that a full strength fillet weld is achieved on studs up to and including 25.4mm diameter (1” diameter). The minimum practical size of fillet weld (5 or 6mm) should ensure a full strength fillet weld for the smaller diameter studs. The main problem with fillet welding around a small diameter is the difficulty in maintaining the correct welding conditions, and severe undercutting on the stud shank may result. Such welds normally have several stop-start positions and where multi-run welding is carried out to achieve the 8mm or 10mm fillet, particular care with the procedure needs to be taken to achieve an acceptable weld quality. The repair weld must be continued at least 10mm beyond the discontinuity being repaired to minimise risk of forming stop/start defects in the zone of imperfection (thus severely weakening the repair weld).

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B5.6.2 Replacement of Unacceptable Welds

B5.6.2.1 ***Studs in Tension Areas.*** When stud failure results in base metal being pulled out in the course of testing or during stud removal, providing the depth of the resultant cavity is not greater than the lesser of 3mm or 5% of the material thickness, the damaged area shall be repaired by an arc welding process carried out in accordance with AS/NZS 1554.1, AS/NZS 1554.4, or AS/NZS 1554.5 as appropriate, prior to grinding.

B5.6.2.2 ***Studs in Compression Areas.*** The provisions of the clause are taken from clause 7.7.5 of AWS D1.1 and have similar requirements to the removal of studs from tension areas. In some cases however, the cavity may be ground out and blended into the surrounding plate without the need to weld repair the cavity.

B5.6.2.3 ***Replacement Studs.*** If replacement studs are to be used for base metals with unacceptable installed studs, the unacceptable studs must be removed and the affected base metal area repaired prior to welding of the stud. The replacement studs must then undergo a bend test of approximately 15° from their original axis.

B6 Testing of Finished Welds

B6.0 General

Welded studs should be inspected visually in the first instance for weld appearance and in some instances should also be tested mechanically, either by bending or by tension.

Visual inspection applies to both non-threaded and threaded studs. The weld fillet around the stud base should be inspected for uniformity and lack of fillet all the way round the stud base. Satisfactory and unsatisfactory stud welds are illustrated in Figure B5.6.1.

Section 6 of Part 2 does not state who is to test the finished welds, but usually this would be carried out by the inspector acting for the principal. The Welding Supervisor, acting for the fabricator may, of course, carry out these tests as part of the fabricator's normal quality control programme.

B6.1 Non-Threaded Studs

If the welding parameters deviate by more than 10% from the target setting on a welding machine that records all weld parameters, or for other machines , if after visual inspection, a questionable weld is evident i.e. a weld that does not show a full 360° fillet or has been repair welded, it must be tested by bending to approximately 15° from its horizontal axis. The studs must be bent in the direction away from the area showing minimal flashing i.e. put a tensile stress on the zone of imperfection. A slow method of application of the bending load is preferred over more severe hammer test method.

Studs that pass the hammer test may be left in place in the bent position (clause 6.3) but studs which fail must be replaced.

The clause and its accompanying notes permit the inspector or principal to select additional studs for testing, the number of which will depend on the whether the structure is statically or dynamically loaded.

B6.2 Threaded Studs

As in the case of non-threaded studs if, after visual inspection, a questionable weld is evident, it must be tested. To test threaded studs, the use of the torque test is required. Such a test is likely to be more time consuming and expensive than the bend test. In this test, a steel sleeve of appropriate size is placed over the stud. A nut of the same material as the stud is tightened against a washer bearing on the sleeve with a torque wrench. This applies a tensile load and some shear on the stud.

The test is performed in a similar manner to that shown in clause 3.3.3.1 with the torsion requirements of Table 3.1 of Part 2 applying. In this case though, the stud is not tested to destruction.

If any of the threaded studs fail this test, an additional two studs shall be similarly tested. If either of these fail, all of the welds represented by the test shall be tested. As with any failure, the weld procedure should be reviewed and checks made to ensure that the qualified procedure was followed.

As with non-threaded studs, the note to the clause permits the inspector or principal to select additional studs for testing, the number of which will depend on the whether the structure is statically or dynamically loaded.

B6.3 Use of Tested Studs

The 2003 edition of Part 2 placed restrictions on the degree of bending permitted if the stud is to be used in the structure. The reason for this is that if the studs are bent significantly beyond 15° their design capacity starts to be reduced. This puts upper limits on the extent of bending that is permissible, for a stud that survives the bend test, for it to still be considered fully effective in design. As the clause states, bent studs that show no sign of failure after the bend test may be left in the bent position, provided the application code permits this. Neither AS 2327.1 nor the Australian Bridge Design Code (Reference 1) have any restrictions on the use of bent studs for composite steel-concrete beams.

B6.4 Additional Testing For Studs Welded to Beams with Adverse Surface Conditions

This clause was inserted in the 2003 edition of Part 2 and requires the fabricator to Ring Test (see clause 1.4.6 in Part 2) all studs welded under adverse conditions i.e. welded when wet, through paints or other surface coatings etc.

B6.5 Unsatisfactory Welds

This clause highlights the obligation of the fabricator to change set-up conditions for welding and make good any required repairs if, in the judgement of the inspection authority or the principal, the progress of work is not in accordance with Part 2 as indicated by testing and inspection.

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Appendix A Matters for Resolution

This Appendix is published as a reference list for the guidance of both principal and fabricator.

Wherever practicable, the matters listed in Appendix A of Part 2 are items which the principal and the fabricator should resolve before the contract is let, so that they form part of the contract documents. Other matters listed need resolution as the contract proceeds.

Testing requirements detailed in section 3.3.1 of Part 2 and B3.3.1 of this commentary should also be clarified under this Appendix.

The background to each of the individual items may be found in this commentary in the comments on the relevant clause.

Appendix C Manufacturer's Stud Base Qualification Requirements

Stud base qualification is carried out for the purpose of giving assurance that the studs as delivered to the fabricator, are capable of producing sound welds.

The responsibility of qualifying the stud base rests with the stud manufacturer and not with the fabricator who will subsequently use the studs on an actual project. The fabricator is entitled to request evidence of such qualification tests. The tests prescribed in this Appendix are essentially the same as those prescribed in Annex IX of AWS D1.1.

Part 2 does not specify who, if anyone, is to supervise the stud manufacturer when these stud base qualification tests are carried out.

The stud base qualification, once obtained, is valid until the stud manufacturer makes any change in stud base geometry (diameter of stud – any increase at all or any decrease by 3 mm; any change in dimensions or shape of stud base) any change in stud base material (i.e. any change in steel grade outside AS 1443) any change in flux type or ferrule type. The stud base qualification is hence quite extensive, and no monitoring is imposed upon the stud manufacturer to ensure that the qualified stud base is being maintained. The stud manufacturer should be in a position to supply evidence that the stud base has not varied from the qualified stud base if so requested.

Welding Procedure No

Fabricator ....

1. Details of Workpiece ....
   (Application)
   Material Standard ....
   (thickness mm)
   Surface Condition ....
   Weld-Through Sheeting ....
2. Details of Studs ....
   (Type/diameter mm)
   Length (mm) ....
   Stud Function ....
   (shear connector or other)
   Stud Base Qualification ....
3. Welding Position ....
4. Details of Equipment
   Power Source ....
   Control Unit ....
   Stud Gun ....
   Welding Cables
   Type ....
   Arrangement ....
   Total Length (m) ....
5. Details of Weld Settings
   Current (A) ....
   Voltage (V) ....
   Cycle Time (min) ....
   Arc Time (s) ....
   Lift (mm) ....
   Plunge (mm) ....

6 Results of Qualification Tests
   Visual examination ....
   Bend tests on first two studs (Passed/Failed) ....
   Tension tests on first two studs (Passed/Failed) ....

7. Details of further test welds if required ....
   ....
8. Additional relevant information ....

Operator's Name .... Approved by ....
.... Date ....

Figure B4.3 A suitable form of Welding Procedure Sheet for Stud Welding

(For use in detailing prequalified welding procedures, recording qualified welding procedures and operator qualifications)

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SECTION C: PART 3 – WELDING OF REINFORCING STEEL

C0 Introduction

A major revision of the 1983 edition of Part 3 was published in October 2002 as AS/NZS 1554 Part 3. The revision of this Standard was undertaken to provide welding rules for reinforcing steels covered by the joint Australian - New Zealand Standard AS/NZS 4671 published in 2001, which superseded a number of reinforcing materials Standards including AS 1302, AS 1303 and AS 1304. The revised reinforcing steels materials standard was modelled on the proposed uniform reinforcing steel standard for Europe, but restricts chemical composition limits to below that set for European countries so as to retain the superior welding characteristics fabricators expect from Australian and New Zealand manufactured reinforcing steel.

The principal changes from the 1983 edition of Part 3 include the necessity for hydrogen controlled (and for butt welds, higher strength) electrodes for many welds, the introduction of single sided lap welds and new types of indirect butt splice welds, and a new classification for welds used for the pre assembly of reinforcing steels. As in the previous edition, preheat will not normally be required for steels made for Australian use (class N steels), however preheat may be required in some cases for the higher carbon equivalent seismic class steels (class E).

C1 Scope and General

C1.1 Scope

AS/NZS 1554 Part 3 covers the welding of reinforcing steel for concrete construction and follows the same basic concept as the other parts of AS/NZS 1554 in that adequate quality is achieved through the use of prequalified consumables, weld preparations and a procedure qualification test.

Part 3 is intended to apply to structures designed and constructed to AS 3600 or NZS 3101.1 and using reinforcing steel complying with AS/NZS 4671. Requirements for Flash Butt and Gas Pressure welding are also included in addition to the more commonly used arc fusion processes.

For New Zealand usage, NZS 3101 should be checked for provisions superseding those of AS/NZS 1554.3 e.g:

- Welding of reinforcing manufactured by the in-line quenched and self-tempered process (QST) is not permitted;
- Lap joints are not permitted for seismic applications; and
- Limitations for butt joints which are expected to develop the ultimate tensile strength of the bar.

C1.4 Definitions

C1.4.15 Types of Splice

The 2002 edition of Part 3 introduced two new splice definitions. These are:

(a) Anchorage splice – a joint designed to join reinforcing steels to base plates

(b) Single-lap splice – a variant on the traditional double-lap splice but welded on one side only.

Testing carried out in support of this revision has shown that single sided lap welds minimise the tendency of the splice to rotate under tensile loads, and this type of lap splice would generally be preferred. Splitting the lap weld into two welds of approximately equal length similarly reduces joint rotation under load (see clause 4.4.4).

A new type of indirect butt splice (B1-1d) is also recommended to minimise joint rotation where welding and construction conditions permit the use of such a joint.

C1.4.16 Welded Joints

The definitions of welded joints were introduced to differentiate between loadbearing joints and joints used to hold reinforcing in position during fabrication, transport, placement and concreting. The definitions are similar to those used in the draft ISO Standard ISO/DIS 17660.

C1.6.2 Limitations of Welding

Tack welds not shown on drawings are permitted, but subject to the requirements of clause 3.3.

New rules for welding on bent portions of the bar and/or subsequent rebending (based on the European approach) were incorporated into the 2002 edition.

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As in previous editions, the restrictions are designed to prevent tack welds introducing weld heat affected zone (HAZ) cracking or causing strain age embrittlement in susceptible grades of reinforcing steel.

C1.8 Joining Reinforcing Steel to Structures

When reinforcing steel is to be welded to structural steel work, welding is to be carried out in accordance with the applicable structural steel welding Standard. This would normally be AS/NZS 1554.1, but other Standards may be used where appropriate including other parts of AS/NZS 1554.

Care should be taken where non-fusion welds are to be made to steel types susceptible to heat affected zone softening, especially those listed in AS/NZS1554.4.

C2 Materials of Construction

This section lists the Standards to which parent materials and consumables should comply. Consumables complying with Standards other than those listed may be used provided that they are firstly qualified for use (Clause 4.5.2) and their use is approved (see Appendix E).

Major changes to the specification and properties of reinforcing steels accompanied the introduction of AS/NZS 4671:2001. These may be summarised as follows:

1. An increase in the yield strength of the commonly used high strength steels from 400/450 MPa (in Australia) and 430/485 MPa (in New Zealand) to 500 MPa.
2. The specification of strengths and ductility properties as statistically determined characteristic values rather than minimum values.
3. The introduction of uniform elongation (A_{gt}) as an important new measure of ductility together with the retention of the *Rm/Re* ratio.
4. Classification of steels according to their ductility class as follows:
   (a) L Class (low ductility) as used for cold formed steels commonly used in fabric, replacing the previously used "W" designation;
   (b) N Class (normal ductility) as commonly used for high strength bars in Australia, replacing the previously used "Y" designation; and,
   (c) E Class (seismic steels) as commonly used in New Zealand.
5. An increase in the carbon equivalent for N class steels compared to the previously used "Y" designation to facilitate the increase in bar strengths.

Apart from the new requirements for bar ductility, little material change was made to the steel characteristics and carbon equivalent for bars with strength designations of 250MPa (for Australian use) and 300MPa (for New Zealand use). Similarly, apart from the increase in strengths and new ductility measures, no significant material changes were made to the cold formed steels commonly used in fabrication.

C3 Details of Fusion Welded Connections

The requirement for lap splice and direct and indirect butt splices are as follows:

The throat size for an indirect butt splice and a lap splice should not be less than one quarter the size of the smaller bar. For a direct butt splice, the throat size should not be less than the size of the smaller bar joined.

Weld width in lap splices should be not less than 0.45 times the size of smaller bar. This minimum finished width requirement provides assurance to the fabricator and inspector that the required throat size of the weld has been achieved.

Minimum effective length of the weld is now directly defined in Table 3.2. For single lap splice joints, the effective length will vary with consumable strength and reinforcing steel grade. For other joint types, full joint strength will be achieved even with the use of lower strength welding consumables as additional length has been included beyond the theoretical minimum necessary to minimise loss of strength due to joint rotation under load.

It should be noted that additional hydrogen controlled consumables complying with parts 1 and 2 of AS/NZS1554.3 are commercially available but were unintentionally omitted from this table. Provided that they comply with the required strength levels as shown in Table 3.2, they may be safely used. See also clause C4.5.1 in this technical Note.

C3.2.1.2 Indirect Butt Splices

Indirect butt splice joints BI-1d and BI-1e using two load transferring bars were introduced in the 2002 edition of Part 3. These joints feature in BS 7123, ISO/DIS 17660 and European Standards and literature, and are often referred to therein as strap joints. Pre-qualification testing for Part 3 of AS/NZS 1554 has shown that they do not suffer from the rotation problems of lap splices, and are able to exceed the full load carrying capability of the parent bar. The primary limitation on their use will relate to the available concrete coverage.

C3.2.2 Lap Splices

Prequalified Single lap splice joints were inserted in the 2002 edition of Part 3. Testing indicated that these joints were better equipped to resist rotation under load because of their additional length. Provided that there is sufficient volume available in the concrete to accommodate the additional length, their use is preferred over the double lap splice. The committee also noted that single lap splice joints were the preferred lap splice form in BS 7123, ISO/DIS 17660 and European Standards. Double lap splices, whilst common in Australia were not consistently mentioned.

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C3.2.3 Anchorage Splices

Anchorage splices were introduced in the 2002 edition of Part 3 to give fabricators guidance when connecting reinforcing bars to plates and structural sections. These joint types also feature in ISO/DIS 17660 where they are referred to as Transverse end plate joints.

C3.3 Non-Loadbearing Welded Joints (Tack Welds)

Welding for the pre-assembly of reinforcement for both conventional reinforced concrete and pre cast concrete construction is now the most common welding operation carried out on reinforcing steels. Accordingly, major changes were made to this section of Part 3 in the 2002 edition. The section now describes two basic types of tack welds, the more substantial conventional tack weld, and tack welds used purely for locating steel work in position prior to the pouring of concrete. Whilst the use of conventional tack welds is preferred, the use of any particular tack weld type remains a matter for resolution (Appendix E).

Requirements for conventional tack welds are set out in Clauses 3.3.1 and 3.3.2, and remain substantially unchanged from similar clauses in the 1983 edition. The addition of a reference to Appendix B and by inference, Figure B1, now provides the fabricator with guidance on how to meet minimum weld size and length obligations on a variety of bar sizes without compromising either weld quality or bar strength.

Tack welds meeting the requirements of clauses 3.3.1 and 3.3.2 do not require qualification testing but the welding conditions used should be documented to ensure reproducibility on future occasions.

When tack welds are subjected to lifting loads in particular, additional care is required and Clause 3.3.3 now requires the designer to give appropriate consideration to the minimum weld size necessary to support the loads encountered during construction and transport without failure. This requirement was introduced to ensure that prefabricated reinforcement cages in particular were able to withstand the rigours of fabrication and handling stresses without catastrophic collapse.

C3.3.4 Locational Tack Welds

To facilitate the development of tack welds used for locational purposes, new requirements were introduced via Clause 3.3.4 and Appendix C in the 2002 edition. As locational tack welds by their nature are not as robust as conventional tack welds (Clauses 3.3.1 – 3.3.3), they should not be used to support lifted loads. Locational tack welds are typically small with short arc times and rapid cooling rates. Qualification testing is required (Appendix C) to ensure that the properties of the reinforcing bar are not adversely compromised.

The use of non-hydrogen controlled consumables is permitted for welds used for locational purposes in contrast with Table 4.11.6 provided that their use is qualified in accordance with Appendix C.

The provision for restriction of carbon equivalent for attached wires, rods and bars is consistent with similar weldability restrictions on backing materials used in conventional welded joints in other parts of AS/NZS 1554.

C4 Qualification of Welding Procedures and Personnel for Fusion Welding

Section 4 follows the basis of the other parts of AS/NZS 1554 in that welding procedures shall be qualified prior to use. Likewise, documented evidence of prior qualification shall also be accepted without further testing.

Adherence to prequalified consumables and preparations reduces qualification testing to the production of a macro specimen. If either a non prequalified preparation or consumable is used then a bend and tensile test is also required. Note that other useful joints types not included in Part 3 can be found in AWS D1.4.

C4.4.4 Prequalified Lap Splices

The provision contained in the note has its origins in BS 7123. The advantage of allowing the splitting of welds in the manner described allows the member to maintain full strength whilst minimising the tendency for lap connections to rotate under load.

C4.5.1 Prequalified Welding Consumables

The welding of the high strength 500MPa class reinforcing steels requires the mandatory use of hydrogen controlled electrodes so as to minimise the risk of hydrogen related delayed cracking problems. Tables 4.5(A) and 4.5(B) details those consumables deemed prequalified for the applicable applications. It should be noted though that other hydrogen controlled welding consumables complying with AS/NZS1553.1 and AS/NZS1553.2 and the required strength requirements are commercially available (e.g. E5515 and E5516 types) but were unintentionally omitted from the tables. Until such time that this anomaly can be corrected by amendment, fabricators wanting to use such electrodes should seek exemption from the Principal for the need to conduct the additional qualification tests required by clause 4.5.2.

C4.10 Qualification of Welding Personnel

Personnel qualification for the Welding Supervisor follows the rules for structural steel work and similarly Welders do not require formal welding certificates. It is however advantageous to use certificated personnel.

Table 4.10.2 like similar tables in other parts of AS/NZS 1554 has its origins in ISO 9606.1.

C4.11.6 Preheat Temperature

Historically reinforcing steels developed their properties by a number of different methods:-

(a) Steel Carbon content;
(b) Cold working of a low carbon steel;

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The production of higher strength grades by route (a) meant that steels of high Carbon Equivalent and consequent poor weldability resulted. Many of these primitive high strength steel types are listed in AWS D1.4 (the relevant ASTM A615, A616 and A617 grades have no chemistry limitations, unlike AS NZS 4671).

Australian and New Zealand manufacturers use two newer methods to obtain higher strengths in low carbon steels:

(c) The use of a high speed water quench and subsequent auto temper (i.e. quench and self temper or QST);

(d) The use of micro alloyed low carbon steels.

Such techniques, particularly (c) produce bars of excellent weldability whilst maintaining good useability.

The 500 MPa steels in ductility class N and E are either low carbon “mill heat treated” or “QST” steels as made by the TEMPCORE or similar process, or low carbon microalloyed steels. The 250 and 300 MPa steels are typically simple low carbon manganese steels, and the 500 MPa steels in ductility class L are typically low carbon cold worked steels

Table 4.11.6 – Minimum Preheat Temperatures follows the WTIA Technical Note 1 concept from Part 1 of AS/NZS 1554 but is presented in a simplified form in the Standard.

Grade 500E steels are in Group 5 according to WTIA Technical Note 1 and require preheat in some circumstances, but all other designations generally require no preheat. Steels in ductility class L are in Group 3, and all other steels are in Group 4. Requirements for interpass temperature control remain, and it is critically important that these limits be observed when welding the “QST” type steels.

For all steel types, and particularly for steel types and welding conditions not listed in Part 3, refer to the bar manufacturer’s published literature or WTIA Technical Note 1 for further guidance.

Note: *The quenched and self tempered steels may have heat input, preheat and interpass temperature requirements that vary from or are not shown in the Standard. The user should therefore check and comply with the bar manufacturer’s weldability recommendations if different from those of Part 3.*

C5 Sections 5 Flash Butt Welding and 6 Flame Pressure Welding

These sections cover the production of direct butt welds only by semi-automatic welding machines.

Flash butt welding is the more established process but is now mainly encountered in places where reinforcing bars are prefabricated before delivery to site. The use of manually controlled flash butt welding machines is not permitted.

Gas Pressure Butt welding is mainly a site erection technique, very commonly used in continental Europe and Japan but not widely seen elsewhere.

Both methods are qualified by means of carrying out two bend and two tensile tests on qualification test prices. Macro testing is not required. Production test welds are required. Two welds are required for bend and tensile testing at the commencement of each production run for Flash Butt welding and each shift for Flame Pressure welding. Additional tests are required during production - one bend and one tensile test for each 100 Flash Butt welds or one bend test only if less than 100 welds are produced.

Flame Pressure welding requires that one additional tensile test per shift be carried out for each welder.

C7 Qualification of Welding Procedure by Testing

The extent of qualification testing required is given in Table 7.2 and requires no explanation.

The bend diameters given in clause 7.3.3 are similar (not identical) to those in ISO/DIS 17660.

C8 Tests

Weld quality requirements were moved to a new Section 9 in the 2002 edition of Part 3, essentially leaving Section 8 to cover mechanical test requirements.

C8.3 Tensile Test Requirements

The values for minimum tensile strength shown in Table 8.3 are based on the specified minimum R_m/R_e values in AS/NZS 4671 for the particular steel designation, as applied to the minimum characteristic values for yield or proof strength. If fracture occurs in the weld zone, simply meeting the minimum tensile strength values shown in Table 8.3 would not necessarily ensure that the minimum specified joint ductility in the bars has been achieved. This can only be guaranteed if fracture occurs outside the weld zone.

Whilst most welds are considered likely to pass this latter requirement, it has not been mandated because it would require direct butt splices in particular to be made with very high strength electrodes (with an increased risk of metallurgical and other problems). This issue is currently under consideration by the relevant Concrete Code Committees and this section may be the subject of a future amendment.

For New Zealand applications where the E-class reinforcing steel is specified, it is recommended that welding consumables be selected to ensure that fracture occurs outside the weld zone. However, due consideration should be given to the additional risks likely to be present if utilising welding consumables with strength classifications beyond those deemed prequalified.

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C8.4 Bend Tests

The former size for bend testing is specified in Clause 7.3.3 The requirement after testing is that no revealed imperfection is greater than 3mm in maximum dimensions.

C9 Quality of Welds

Weld qualities during both qualification testing and for production testing and inspection are given in Section 9. The weld quality is equivalent to Category SP of Part 1 i.e. free from cracks and loss of area exceeding 5%. Weld reinforcement is limited to 3mm except in the case of Flame Pressure welding where the diameter of the upset after welding is specified as a minimum of 1.3 times bar size. No maximum is specified.

C10 Inspection

Section 10 is similar to the Inspection Section in other Parts of AS/NZS 1554 and requires no further comment except perhaps to point out that no guidance is given on the extent of testing since it was felt that only visual inspection is normally warranted on welds in reinforcing steel.

Appendix B Recommended Tack Welds for Locational Purposes

Appendix B is based on a similar section in BS 7123 and diagrammatically describes how a fabricator can meet the minimum weld size requirements of Clause 3.3.2 without having to invoke the requirements of Clause 3.3.4. Subject to meeting all the requirements of Clause 3.3.3, they may also be suitable to carry lifting loads.

Appendix C Locational Tack Welds – Test Methods and Performance Requirements

This appendix (based on ISO/DIS 17660) describes the requirements for the new welded joint classification designed principally for the pre assembly of reinforcement cages and structures. These welds are intended to be non-loadbearing, and take no part in the structural design. The procedures and testing requirements for qualifying these welds are intended to ensure no deleterious effects on the reinforcing steel properties, rather than evaluate any aspect of weld or joint performance.

Test welds for locational tack welds need only be weld deposits of the size intended for the subsequent welding operation. It is not necessary to make actual joints, and the use of simple weld deposits will simplify testing.

Once qualified, no further testing is required provided there is no change to steel type (i.e. microalloyed, QST or cold worked steels within the same strength designation), bar size, welding process and conditions and weld size.

Provided no other changes to Essential Variables are made and heat inputs do not exceed 2.5 kJ/mm, larger weld sizes are automatically permitted provided the new weld procedure is fully documented with reference to the original weld procedure qualification. For smaller weld sizes, full qualification testing is required (Clause C7).

Careful selection of the test bar diameters and adherence to the limits of essential variables will ensure that the amount of testing required is minimised (see Table 4.9(A) item (p)), potentially as few tests as one bar diameter within each size range.

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Section D: Part 4 – Welding of High Strength Quenched and Tempered Steels

D1 Scope and General

Part 4 of AS/NZS 1554 was originally published in 1989 to provide guidance on the fabrication of high strength quenched and tempered (Q&T) steels. At that time, such steels were widely used and produced in substantial tonnages in Australia to proprietary specifications. Whilst these steels are now manufactured to AS 3597, they are not included in the design provisions of AS 3990, AS 4100 and NZS 3404 as these Standards are only applicable to steels with a specified minimum yield strength of up to 450MPa. However, AS 4100 and NZS 3404 may be used for preliminary design as ongoing research is showing the provisions of these standards to be typically appropriate.

AS/NZS 1554.4 was published to provide the basis for contractual specification of the use of this class of materials. It was prepared to closely parallel the structure and concept of Part 1 and thus this discussion will be restricted to differences between Part 4 and Part 1. It should therefore be noted that the 2004 edition of Part 4 incorporates relevant changes undertaken in both the 2000 and 2004 editions of Part 1.

Part 4 is directed to the use of Q&T steels for load bearing structural purposes, but it should be pointed out that these materials are commonly used for resistance to wear and abrasion. If information is required for such uses, reference should be made to the steel manufacturer's advice and WTIA Technical Note 15.

Although closely paralleling Part 1 this part contains a number of significant differences mainly arising from the welding and metallurgical differences between Q&T steels and the pearlitic C/Mn steels of Part 1.

These are:

(a) Only hydrogen controlled (low hydrogen) welding consumables are permitted;

(b) Brittle Fracture is much less of a problem with Q&T steels under the normal temperature ranges encountered in Australia and New Zealand and under most circumstances no special consideration is required for structures operating above -10°C;

(c) Preheat and interrun (interpass) temperatures are defined in terms of maximum and minimum rather than the minimum only in Part 1;

(d) Part 4 includes three weld categories to encompass static and fatigue loading conditions and in this regard is similar to AS/NZS 1665.

Hydrogen controlled consumables only are permitted because of the increased hardenability of the weld heat affected zones. This also has the beneficial effect of limiting the risks associated with hydrogen induced weld metal cracking.

D1.1 Scope

Part 1 covers the same range of welding processes as Part 1 but notes that Electroslag and Electrogas welding processes may not be suitable for Q&T steels. This is because the heat input of these processes may exceed the maximum allowed under this Part for certain steel grades and thus lead to undesirable properties in the weld Heat Affected Zone. It should, however, be noted that some steel makers produce Q&T steel grades specifically designed for high heat input welding processes, although these are not included in the materials of construction listed in Part 4 as they are proprietary specifications and not national Standards.

D1.6 Weld Categories

Three weld categories are detailed.

(a) GP (General Purpose) for use where loading is static and not greater than 50% of that allowed by the referenced design standard.

(b) SP (Structural Purpose) for use where static loads greater than allowed in GP Category or dynamic (i.e. fatigue) loads not exceeding the limits of AS 4100 and NZS 3404 or 80% of that allowed by AS 3990 for a Category B detail.

(c) FP (Fatigue Purpose) should only be used for high levels of dynamic loads greater than allowed for Category SP i.e greater than detail category 112 of AS 4100 and NZS 3404.1 or where they exceed 80% of the permissible stress range for category B of AS 3990.

It might very well seem strange that the fatigue rules of AS 3990, which has a material yield upper limit of 450 MPa, should be involved for these steels which exhibit yields between 500 and 800 MPa. The explanation is that under high cycle fatigue conditions all steels, irrespective of strength, have much the same fatigue strength.

Under low cycle loading conditions the Standards will be rather conservative.

D2 Materials of Construction

D2.1 Parent Material

Since Australian Standards, as a rule, refer only to Australian and other national Standards rather than proprietary specifications, Part 4 lists only AS 3597, ISO 4950/3, ASTM A 514 and ASTM A 517 and imposes a yield limit of 800 MPa.

The 2004 edition of Part 4 introduced methods of assessing non-complying steel types in clause 2.1, specifically either testing to determine compliance (item (i)) examination of properties shown on manufacturer's test certificates (item (ii)). Equivalence as provided in clause 2.1 (c) is to be determined by either of these methods noting that additional impact tests may be required to establish compliance with Appendix B of Part 4.

D3 Details of Welded Connections

Section 3 is identical with that in Part 1 and the only point worthy of special note is that Part 4 permits the use of plug and slot welds (subject of course to the other provisions of Part 4). Clause 2.9.4 of AWS D1.1 prohibits the use of these details on Q&T steels.

Plug and slot welds are perhaps more commonly used on the wear resistant grades of Q&T steels which are strictly not covered by Part 4.

D4 Qualification of Procedures and Personnel

Section 4 is again very similar to the same section in Part 1. Where Q&T steels are to be welded to structural steels grades covered by Part 1 welding is to be carried out in accordance with Part 1 except that:-

(a) only hydrogen controlled consumables are allowed (Q&T steels cannot be satisfactorily welded by non-hydrogen controlled welding consumables); and

(b) the Preheat and interrun (interpass) temperature requirements of both Part 1 and Part 4 must be satisfied.

Part 1 requires a minimum preheat and arc energy generally with no upper limit, whilst Part 4 requires a minimum preheat and imposes a maximum on arc energy and interpass temperature. It will generally be possible to satisfy both sets of requirements by restricting the maximum arc energy used.

Note that this provision also means that the strength of the welding consumable selected need only match the requirements of the lower strength steel being welded to Part 1 of AS/NZS 1554 e.g. when welding AS/NZS 3678 grade 350 to AS 3597 grade 700, use a hydrogen controlled consumable selected from Table 4.6.1(A) of Part 1.

See WTIA Technical Note 15 for further information on these points.

D4.6 Qualification of Welding Consumables

D4.6.1 Prequalified Welding Consumables

Part 4 lists prequalified consumables for MMAW, GMAW, FCAW and SAW in the appropriate upper range of yield strengths, however the 2004 edition of Part 4 (clause 4.6.1.2) permits the use of lower strength consumables when sanctioned by the designer. As noted earlier, only hydrogen controlled consumables are permitted and so only such grades are listed as prequalified.

Steel grades are listed as steel types 8, 9 and 10 with Part 1 listing types 1 to 8.

The remainder of section 4 closely follows Part 1 with the difference relating to the change in steel properties as follows:-

(a) Table 4.6.2. Mechanical properties for non prequalified weld metal. The values tabulated were amended to align with those published in AS 3597 in the 2004 edition of Part 4.

(b) Clause 4.7.6 Bend test requirements change to bring them into line with plate requirements.

(c) Clause 4.7.9 HAZ Hardness change from 350 HV10 to 450 HV10.

D5 Workmanship

This section differs in only two respects from Part 1:-

(a) 5.2.2 Alignment of butt welded joints

Weld categories SP and GP are unchanged from Part 1 but in category FP the permissible misalignment is halved to 5% of plate thickness or 1.5mm in order that the fatigue resistance of the joint is not compromised.

(b) 5.3 Preheat and Interrun Temperatures

Changes were made to this section in the 2004 edition of Part 4. These changes include use of the concept of combined thickness, and the aligning of preheat, interpass temperatures and heat input requirements given in Table 5.3.4 with those published in WTIA Technical Note 15. It is important to note that quenched and tempered steels from different manufacturers are manufactured using different alloy compositions, and as such, may require preheat and interrun temperatures unique to that manufacturer. As many such Q&T steels are manufactured from steels utilising very lean chemistries, lower values of preheat than those published in Table 5.3.4 are required. The conditions of Table 5.3.4 therefore only apply where such manufacturer's data is not available.

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Note also that in many cases, manufacturer's data tables apply only to butt welds in plates of equal thickness. For all other conditions, the joint combined thickness should be calculated as given in this section and WTIA Technical Note 15, and then divided by 2. This will provide the user with an equivalent butt weld in plates of equal thickness.

D6 Quality of Welds

This section of Part 4 is readily understood although superficially different in appearance due to the three weld categories in this part of the Standard. However, the requirements for categories SP and GP are exactly the same as in Part 1, whilst category FP is the same as in AS/NZS 1554 Part 5 with the exception of loss of area restrictions.

For an explanation of category FP see section E of this Technical Note dealing with Part 5.

As noted in section A6.2 of this Technical Note, NDE technicians and fabricators alike should be aware of the time dependent nature of hydrogen cracking in particular and allow sufficient time to elapse after the cessation of welding before conducting NDE examinations to detect the presence of developing cracks. Whilst 48 hours is preferred for conventional structural steels, Pargeter (Reference 11) recommended a minimum of 72 hours for Q&T steels due to the continued detection of new and growing cracks within this time frame.

Appendix B Brittle Fracture

This appendix, modelled on the equivalent section of Part 1, was introduced into the 2004 edition of Part 4 to provide guidance to end users on utilising Q&T steels at low temperatures.

Brittle fracture is known to be much less of a problem with Q&T steels under the normal temperature ranges encountered in Australia and New Zealand and under most circumstances no special consideration is required for structures operating above -10°C. The reason for this is that these steel types are manufactured to Standards which require guaranteed impact properties at very low temperatures, for example the AS 3597 grades are impact tested at -20°C with grade 700 having a guaranteed minimum Charpy average impact energy of 40J.

Part 4 provides a measure of conservatism in this regard, although it is true that the intention of Table 5.3.4 is in part to ensure that the weld HAZ is not further embrittled.

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Section E: Part 5 – Welding of Steel Structures Subject to High Levels of Fatigue Loading

E1 Scope and General

In the mid 1970s, when it was decided to introduce graded levels of weld quality into Australian standards for structural steel, it was envisaged that there would be a specified quality for fatigue loading.

This concept proved to be very unpopular with the fabrication industry who felt that higher quality would be specified unnecessarily and greatly increase the cost of steel fabrication.

Although the concept of a fatigue resistant weld quality was readily accepted in the parallel Standard for Aluminium (AS/NZS 1665) the industry objection to such a concept in steel codes had some basis since the selection of weld category was a mandatory process in AS/NZS 1665. It was to be advisory in AS/NZS 1554 and thus could well have lead to the predicted over specification of the fatigue category.

The 1980 edition of AS/NZS 1554.1 therefore excluded a fatigue category and it was necessary to limit its application to levels of loading such that the imperfections allowed in SP category did not lead to failure in the design life of the structure.

At the time of preparation of the 1980 version it was thought that elimination of surface imperfections such as reinforcement, under cut and exposed porosity would be sufficient to achieve the required level of fatigue resistance as will be discussed below. Current knowledge of fatigue failure has shown that a reduction in levels of internal imperfections is also desirable.

Part 1 of AS/NZS 1554 restricts category SP fatigue loading to 80% of the stress range allowed by AS 3990 for category B weld details, or a stress range not exceeding that permitted for Detail Category 112 in AS 4100. This limitation was in fact of little real significance since very few welded structures are loaded to greater levels, possibly only some rail bridges, cranes and machinery and offshore platforms.

Part 5 and the FP category in Part 4 were prepared to fill the gap at the upper fatigue levels allowed by AS 3990 but more importantly to serve the alternative to AS 3990, the limit state Standards AS 4100 and NZS 3404.

The fatigue provisions of AS 4100 and NZS 3404 follow the current European fatigue design concepts and include a rule to reduce the permissible stress range when plate thickness exceeds 25mm.

E2 Materials of Construction

This section follows Part 1 closely and the changes in the 2004 edition reflect the changes in steel Standards shown in Part 1:2004, and the additional requirements for non-complying steel types.

E3 Details of Welded Connections

This section does not differ in concept from Part 1 but includes only rules for welded types which would be permitted under high levels of fatigue loading and thus does not deal with Seal Welds, Plug and Slot Welds and welds for the purpose of combining rolled hollow sections (clauses 3.5, 3.6, 3.7 and 3.8 in Part 1).

Transitions of thickness or widths are changed to a taper limit of 1:4 instead of the much steeper 1:1 of Part 1.

E4 Qualification of Procedures and Personnel

This section is basically identical with that in Part 1 except that the rules for welds in hollow sections (clause 4.5.5 of Part 1) have been omitted as it was not felt that the relaxations allowed in Part 1 for hollow sections were applicable to high levels of fatigue loading. This of course does not imply that hollow sections should not be used under fatigue loading conditions but only that welding should be carried out to the weld quality specified in Part 5.

The requirement in the 1995 edition of Part 5 for all weld procedures to be made available to the principal's representative for approval was removed in the 2004 edition.

E5 Workmanship

The Workmanship section differs from Part 1 only in respect to clause 5.2.2, Alignment of Butt Joints, in which permissible misalignment is limited to the lesser of 5% or 1.5mm which is 50% of that allowed in Part 1.

Table 5.3.4(A) deals with the steel Standards and was updated by amendment 1 in 1998, and again in the 2004 edition. Prior to the amendment, the steel Standards referenced by this Table in Part 5 varied from those published in Part 1 because of the differing publication dates of the two documents. Up until the amendment, it was necessary to refer to Part 1:1995 for Weldability Group Numbers for steel Standards and types not listed in Part 5. Should this discrepancy arise again in the future, reference can again be made to the equivalent Table in Part 1

The alternative method of preheat calculation given in section 5.3.4 of Part 1, using the steel manufacturer's ladle or heat analysis, was intentionally not covered in amendment 1 of 1998 but was introduced into Part 5 in the 2004 edition.

E6 Quality of Welds

Section 6 is the core of Part 5 and is intended to define a weld quality adequate for the maximum loadings permitted by AS 3990, AS 4100 and NZS 3404.

It is very important to understand that the Standard must be taken as a whole, particularly in respect to material and welding consumables selection, to avoid any danger of brittle fracture. It is also necessary that the rules relating to weld heat input and preheat be observed to avoid a hardened HAZ causing premature failure.

It should not be thought that the Standard will prevent fatigue cracking as this is not practicable but is intended to provide a weld quality such that a fatigue crack will not reach a size sufficient to endanger the structure during the life of the structure. Since parent material and weld metal are chosen to be notch ductile, the fatigue provisions are based on the premise that a through-thickness crack up to three times plate thickness in length is tolerable.

E6.1 Methods of Inspection and Permissible Levels of Imperfections

Effectively no surface imperfections are allowed and to achieve this it will be normal to dress at least the weld toes. This is typically done by either remelting the weld toes with a GTAW torch (commonly referred to as Tiging the toes) or by grinding. In the 1989 edition, the then Table 6.1 (Table 6.1.2 in the 2004 edition) noted that undercut less than 0.5mm in depth could be removed by smooth blending. This notation was removed in the 1995 edition due to it being more effectively covered by clauses 5.8.1, 5.8.2 and 5.8.3.

No 'Loss of Area' restriction is included in Table 6.1.2 although a figure of 3% is listed in the corresponding rule in Part 4.

E6.2 Radiography

As mentioned above, it had originally been thought that internal imperfections to the same level as Part 1 would be permissible, but the use of a number of computer packages dealing with fatigue propagation showed that this was incorrect. The values adopted were half those allowed under static loading and thus roughly equivalent to the 3% Loss of Area of Part 4.

The significance of weld imperfections depends upon the nature of the loading. Surface imperfections are the more important in high cycle fatigue and internal imperfections under low cycle conditions. The values given in Part 5 are centred around a fatigue life of 1-2 million cycles and may be inappropriate at fatigue levels lower than 100,000 cycles although in this area the maximum load provisions of the design Standard will provide a safety factor.

As mentioned in section D6 of this Technical Note, weld category FP of Part 4 is virtually identical in acceptance criteria to Part 5 and whilst this is valid for high cycle fatigue under low cycle conditions differences appear which are not embodied in the Standard.

It is recommended that under these circumstances specialist advice should be obtained.

E6.3 Ultrasonic Examination

The comments of section E6.2 above apply equally to both Radiography and Ultrasonic Examination.

E7 Inspection

E7.4 Non-Destructive Examination Other Than Visual

As might be anticipated with the increasing importance of surface imperfections, the suggested extent of non-destructive examination recommended in Table 7.4 is 100% Magnetic Particle inspection and between 50 and 100% Radiography or Ultrasonics.

Appendix D Checklist of Matters for Discussion

The equivalent Appendix in Part 1 of AS/NZS1554 is entitled Matters for Resolution. Whilst most items are similar to those of Part 1, items (o) and (v) are worthy of mention.

Weld treatment to improve fatigue performance

There are a number of recognised methods for reducing the risk of fatigue initiating at the weld toes and other positions (see also section A5.7.2 of this Technical Note). For weld toes these are in order of general preference:

(a) Using a welding procedure that results in weld toes with an included angle of not more than 20° and without undercut;

(b) Deburring locally to ensure that the toes are as in (a) above;

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(c) Remelting of the weld toes using a GTAW torch (i.e. Tiging the toes);
(d) Dressing the weld toe by grinding;
(e) Peening of the weld toes; and,
(f) A combination of the above.

These methods are effective if done correctly, and methods (b) to (f) above have the dual affect of reducing the stress concentration and removing inherent flaws commonly present at the weld toes. Methods (b) to (d) (or combinations of these) may also be used to extend the fatigue life of a joint when cracking has been detected at an early stage.

Method (a) can be the most economic by reducing the stress concentration at the weld toe. It can be achieved by the right combination of welding variables, consumables, weld sequence and position.

Methods (b) and (d) are effective as they both modify the stress concentration pattern at the weld toe. Method (b) uses a rotary conical tungsten carbide burr to correct the toe shape whilst removing the minimum amount of metal necessary, and preferably machining to ~0.5mm below any undercut present so as to produce a smooth transition from the plate surface to the weld. It is important though to ensure that all machining marks lie transverse to the weld toe. Method (d) uses a disc grinder to achieve a similar effect. In both cases in is recommended that the dressed areas be examined using either the magnetic particle or liquid penetrant method.

Method (c) relies on removing local irregularities and imperfections in or near the weld toes and reshaping (i.e. blending) the toes through localised remelting. It also has the beneficial effect of reducing the stress concentration in the area remelted. It should be noted though that adherence to the requirements of Clause 5.3 of Part 5 in terms of arc energy, preheat and interpass temperature are essential to avoid producing a hardened heat affected zone with its inherent risk of the initiation of hydrogen assisted cold cracking in this region. This method is therefore useful with thinner sections where dressing could produce excessive thinning.

Method (e), if done correctly, imparts compressive stresses into the weld toe surface thereby providing an impediment to the initiation of fatigue. This method though is not sanctioned by Clause 5.7.3 of Part 5, as the peening operation itself is prone to quality control problems and in some cases may introduce surface cracks. Cracks once present will negate the beneficial effects of the peening operation.

Whilst plate thickness may be reduced in the weld toe regions by the above methods, the improvement in stress concentration associated with weld toes is less severe than that of the original weld toe thus from the fatigue perspective the loss of section is usually beneficial where the thinning is than ~5% of section thickness.

It should be noted however that weld toe dressing should not be assumed to be effective in the presence of a corrosive medium which can cause pitting in the dressed region and thus initiate a fatigue crack from the pitting, however toe dressing facilitates NDT which can reduce the risk of significant imperfections – especially in crack sensitive steels and thick sections.

Other fatigue sites

As the above toe dressing methods only affect the fatigue strength of the welded joint at the weld toe, the possibility of fatigue crack initiation due to other weld features should not be overlooked. Such features commonly include but are not limited to:

(a) The weld root in a fillet weld;
(b) The presence of weld stop-starts in high stress areas (they should be avoided);
(c) For fillet or compound welds, concave or flat weld profiles are preferred to convex profiles;
(d) Weld ripples should be reasonably smooth and ideally similar in appearance to the class 1 flame cut replica shown in WTIA Technical Note 5;
(e) Arc strikes should be avoided or removed by shallow grinding, blending with the surrounding surface and demonstrated to be free of cracks via either a magnetic particle or liquid penetrant examination;
(f) All weld craters should be filled and free of cracks and underfill;
(g) For short welds, it may be preferable to carry the weld around the end of the plate and terminate welds on the ends of attachments in a lower stressed area, and thus providing a distinct weld toe to be dressed;
(h) At the ends of intermittent or tack welds;
(i) Unwelded strips in backing strips or bars,

Use of weld treatments

These methods apply for weld toes which are transverse to significant stress fluctuations e.g. Figures 16-28, end weld of Figure 29, Figures 35-37 in Table 11.5.1(2) of AS 4100. These methods are not needed for the other Figures.

For further reading on the subject, refer to References 26 and 27.

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References and Bibliography

R1 Standards

Australian and New Zealand standards

Reference should always be made to the latest issue of a standard.

AS 1074	Steel tubes and tubulars for ordinary service
AS 1101	Graphical symbols for general engineering
AS 1101.3	Part 3: Welding and non-destructive examination
AS 1163	Structural steel hollow sections
AS 1167	Welding and brazing-Filler metals
AS/NZS 1167.2	Part 2: Filler metal for welding
AS 1171	Methods for magnetic particle testing of ferromagnetic products and components
AS/NZS 1200	Pressure equipment
AS 1210	Pressure vessels
AS 1228	Boilers-Water-tube
AS 1391	Methods of tensile testing of metals
AS 1418	Cranes (including hoists and winches)
AS 1442	Carbon steels and carbon-manganese steels-Hot-rolled bars and semi-finished products
AS 1443	Carbon steels and carbon-manganese steels: Cold-finished bars
AS 1448	Carbon steels and carbon-manganese steels-Forgings (ruling section 300mm maximum)
AS 1450	Steel tubes for mechanical purpose
AS 1470	Health and safety at work-Principles and practices
AS 1548	Steel plates for pressure equipment
AS/NZS 1553	Covered electrodes for welding
AS/NZS 1553.1	Part 1: Low carbon steel electrodes for manual metal-arc welding of carbon and carbon-manganese steels
AS/NZS 1553.2	Part 2: Low and intermediate alloy steel electrodes for manual-metal arc welding of carbon steels and low and intermediate alloy steels
AS/NZS 1554	Structural steel welding
AS/NZS 1554.1	Part 1: Welding of steel structures
AS/NZS 1554.2	Part 2: Stud welding (Steel studs to steel)
AS/NZS 1554.3	Part 3: Welding of reinforcing steel
AS/NZS 1554.4	Part 4: Welding of high strength quenched and tempered steels
AS/NZS 1554.5	Part 5: Welding of steel structures subject to high levels of fatigue loading
AS/NZS 1554.6	Part 6: Welding stainless steels for structural purposes
AS/NZS 1594	Hot-rolled steel flat products
AS/NZS 1595	Cold-rolled, unalloyed, steel sheet and strip
AS/NZS 1665	Welding of Aluminium Structures
AS 1710	Non-destructive testing:- Ultrasonic testing of carbon and low alloy steel plate- Test methods and quality classification
AS 1796	Certification of welders and welding supervisors
AS 1817	Metallic materials-Vickers hardness test
AS 1858	Electrodes and fluxes for submerged arc welding
AS 1858.1	Part1: Carbon steels and carbon-manganese steels

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AS 1988	Welding of steel castings
AS 2062	Methods for non-destructive penetrant testing of products and components
AS 2074	Steel castings
AS 2085	Magnetic particle testing media
AS 2177	Non-destructive testing-Radiography of welded butt joints in metal
AS 2177.1	Part 1: Methods of test
AS 2177.2	Part 2: Image quality indicators (IQI) and recommendations for their use
AS 2203	Cored electrodes for arc-welding
AS 2203.1	Part 1: Ferritic steel electrodes
AS 2205	Methods for destructive testing of welds in metal
AS 2205.2.1	Method 2.1: Transverse butt tensile tests
AS 2205.3.1	Method 3.1: Bend tests – Transverse guided bend test
AS 2205.5.1	Method 5.1: Macro metallographic test for cross-examination
AS 2205.6.1	Method 6.1: Hardness tests – Weld joint hardness test
AS 2205.7.1	Method 7.1: Charpy V-notch impact fracture toughness test
AS 2207	Non-destructive testing-Ultrasonic testing of fusion welded joints in carbon and low alloy steel
AS 2214	Certification of welding supervisors-Structural steel welding
AS 2327	Composite structures
AS 2327.1	Part 1: Simply supported beams
AS 2717	Welding-Electrodes-Gas metal-arc
AS/NZS 2717.1	Ferrite steel electrode
AS 2812	Welding, brazing and cutting of Metals ^ Glossary of terms
AS 2980	Qualification of arc-welders for welding of steels
AS 3600	Concrete structures
AS/NZS 3678	Structural steel ^ Hot-rolled plates, floor plates and slabs
AS/NZS 3679	Structural steel
AS/NZS 3679.1	Part 1: Hot-rolled bars and sections
AS/NZS 3679.2	Part 2: Welded I sections
AS/NZS ISO 3834	Quality requirements for welding-Fusion welding for metallic material
AS/NZS ISO 3834.1	Part 1: Guidelines for selection and use
AS/NZS ISO 3834.2	Part 2: Comprehensive quality requirements
AS/NZS ISO 3834.3	Part 3: Standard quality requirements
AS/NZS ISO 3834.4	Part 4: Elementary requirements
AS 3978	Non-destructive testing – Visual inspection of metal products and components
AS 3990	Mechanical equipment-Steelwork
AS/NZS 3992	Boilers and pressure vessels – Welding and brazing qualification
AS 3998	Non-destructive testing-Qualification and certification of personnel-General Engineering
AS 4041	Pressure piping
AS 4100	Steel structures
AS 4100	Supplement 1 – Steel structures – Commentary
AS/NZS 4360	Risk management
AS 4413	Steel tubes-Pressure application-Flash butt welding
AS 4458	Pressure equipment-Manufacture
AS/NZS 4600	Cold-formed steel structures
AS/NZS 4671	Steel reinforcing materials
AS 4882	Shielding gases for welding
AS/ISO 13916	Welding-Guidance on the measurement of preheating temperature, interpass temperature and preheat maintenance temperature.
NZS 3404.1	Steel structures standard
NZS 3404.2	Commentary to steel structures standard
NZS 3415	Hot-rolled products of non-alloy structural steels – Technical delivery conditions

American Welding Society Standards

ANSI/AWS C1.1	Recommended practices for resistance welding
ANSI/AWS C1.3	Recommended practices for resistance welding coated low carbon steels
ANSI/AWS C5.4	Recommended practices for stud welding
ANSI/AWS D1.1	Structural Welding Code – Steel (including commentary)
ANSI/AWS D1.3	Structural Welding Code – Sheet Steel
ANSI/AWS D1.4	Structural Welding Code – Reinforcing Steel

British Standards

BS 7910	Guide on methods of assessing the acceptability of flaws in fusion welded structures

ISO Standards

ISO 9606	Approval testing of welders-Fusion welding
ISO 9606.1	Part 1: Steels
ISO 9712	Non-destructive testing-Qualification and certification of personnel
ISO 10721.1	Steel structures-Part 1: Materials and Design
ISO 13918	Welding-Studs for arc stud welding
ISO 14555	Welding-Arc stud welding of metallic materials

R2 WTIA Technical Notes

Technical Note 1	– Weldability of Steels, 1996
Technical Note 3	– Care and Conditioning of Arc Welding Consumables, 1994
Technical Note 5	– Flame Cutting of Steels, 1994
Technical Note 6	– Control of Lamellar Tearing, 1985
Technical Note 7	– Health and Safety in Welding, 1998
Technical Note 8	– Economic Design of Weldments, 1979
Technical Note 10	– Fracture Mechanics, 2002
Technical Note 15	– Welding and Fabrication of Quenched and Tempered Steels, 1996
Technical Note 16	– Welding Stainless Steels, 1985
Technical Note 19	– Cost Effective Quality Management for Welding, 1995
Technical Note 22	– Welding Electrical Safety, 2003

R3 Application Standards

1. Australian Bridge Design Code: Section 6 – Code, Steel and Composite Construction

R4 ASI Publications

2. A. A. Syam (ed), "A Guide to the Requirements for Engineering Drawings of Structural Steelwork, Steel Construction", **29** (3), Sept. 1995.
3. Economical Structural Steelwork, 4th Edition, 1997
4. Standardized Structural Connections, 3rd Edition, 1985
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R5 General References

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R6 Further Reading

Many of the references in this section were listed in previous editions of this Technical Note but not specifically referred to this edition. They are presented here for the information of the reader.

1. Quality Assurance and the Fabricator (withdrawn), Australian Steel Institute.
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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.

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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.

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

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

TN 12-96 – Minimising Corrosion in Welded Steel Structures

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

TN 13-00 – Stainless Steels for Corrosive Environments

(A Joint publication with ACA)

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

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

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

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

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

TN 16-85 – Welding Stainless Steel

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

TN 17-86 – Automation in Arc Welding

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

TN 18-87 – Welding of Castings

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

TN 19-95 – Cost Effective Quality Management for Welding

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

TN 20-04 – Repair of Steel Pipelines

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

TN 21-99 – Submerged Arc Welding

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

TN 22-03 – Welding Electrical Safety

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

TN 23-02 – Environmental Improvement Guidelines

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

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

Provides instruction and guidance to enable Australian companies to:

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

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

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

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

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

WTIA Management Systems

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

Welding Occupational Health, Safety & Rehabilitation Management System

MS02-OHS-01 OHS&R Managers Handbook

MS03-OHS-01 OHS&R Procedures

MS04-OHS-01 OHS&R Work Instructions

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

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

WTIA Pocket Guides

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

PG01-WD-01 Weld Defects

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

PG02-SS-01 Welding of Stainless Steel

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

Other Expert Technology Tools

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

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

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

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