AS 1085.20:2019

Railway track material, Part 20: Welding of steel rail

RISSB RAIL INDUSTRY SAFETY AND STANDARDS BOARD

Infrastructure Standard

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This Australian Standard® AS 1085.20 Railway track material, Part 20:
Welding of steel rail was prepared by a Rail Industry Safety and Standards Board (RISSB) Development Group consisting of representatives from the following organisations:

TBC

The Standard was approved by the Development Group and the Infrastructure Standing Committee in Select SC approval date. On Select Board approval date the RISSB Board approved the Standard for release.

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Development of the Standard was undertaken in accordance with RISSB's accredited process. As part of the approval process, the Standing Committee verified that proper process was followed in developing the Standard

RISSB wishes to acknowledge the positive contribution of subject matter experts in the development of this Standard. Their efforts ranged from membership of the Development Group through to individuals providing comment on a draft of the Standard during the open review.

I commend this Standard to the Australasian rail industry as it represents industry good practice and has been developed through a rigorous process.

Chief Executive Officer
Rail Industry Safety and Standards Board

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AS 1085.20:2019

**Railway track material, Part 20:
Welding of steel rail**

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This Standard was prepared by the Rail Industry Safety and Standards Board (RISSB) Development Group AS 1085.20 Railway track material, Part 20:
Welding of steel rail. Membership of this Development Group consisted of representatives from the organisations listed on the inside cover of this document

Objective

The objective of this Standard is to provide owners and maintainers of railway track with specifications for and means of qualification of welding procedures for use with rail steel in railway track.

This Standard does not address the conditions under which the procedures that are described are to be used.

This Standard is not intended to cover welding of worn rails using flash butt or aluminothermic welds. However, the principles and procedures may be adapted for the welding of worn rails.

It is not intended to cover existing welds.

This Standard is Part 20 of the AS 1085 (Railway track material) series.

Compliance

There are two types of control contained within Australian Standards developed by RISSB:

1. Requirements.
2. Recommendations.

Requirements – it is mandatory to follow all requirements to claim full compliance with the Standard. Requirements are identified within the text by the term 'shall'.

Recommendations – do not mention or exclude other possibilities but do offer the one that is preferred. Recommendations are identified within the text by the term 'should'.

Recommendations recognise that there could be limitations to the universal application of the control, i.e. the identified control is not able to be applied or other controls are more appropriate or better.

For compliance purposes, where a recommended control is not applied as written in the standard it could be incumbent on the adopter of the standard to demonstrate their actual method of controlling the risk as part of their WHS or Rail Safety National Law obligations. Similarly, it could also be incumbent on an adopter of the standard to demonstrate their method of controlling the risk to contracting entities, or interfacing organisations where the risk may be shared.

Controls in RISSB standards address known railway hazards are addressed in an appendix.

Contents

Appendix Contents

1 Scope and general

1.1 Scope

This Standard specifies requirements for the qualification of welds in steel rail manufactured in accordance with AS 1085.1 or rails that are shown to be metallurgically compatible, for use in railway track. The following welding processes are covered:

(a) Joining of rails by flash butt welding or aluminothermic fusion welding.

(b) Repair of the railhead by arc welding or aluminothermic fusion welding.

The Standard does not provide strength properties of welds for use in design nor cover the welding of austenitic manganese steels.

NOTES:

1. Rail steel is considered to be very difficult to weld for structural purposes. Welded rail should not be used in applications other than railway track.
2. Rail produced to specifications other than AS 1085.1 will require a separate qualification process. Appropriate testing will also need to be determined.

1.2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document:

- AS 1003 Engineers' straightedges (metric units)
- AS 1085.1 Railway track materials, Part 1: Steel rails
- AS 1199.0 Sampling procedures for inspection by attributes, Part 0: Introduction to the ISO 2859 attribute sampling system
- AS 1199.1 Sampling procedures for inspection by attributes, Part 1: Sampling schemes indexed by acceptance quality limit (AQL) for lot-by-lot inspection
- AS 1816.1 Metallic materials—Brinell hardness test, Part 1: Test method (ISO 6506-1:2005, MOD)
- AS 1817.1 Metallic materials—Vickers hardness test, Part 1: Test methods (ISO 6507-1:1997, MOD)
- AS 2083 Calibration blocks and their methods of use in ultrasonic testing
- AS 2193 Calibration and classification of force-measuring systems
- AS 2205.5.1 Methods for destructive testing of welds in metal, Method 5.1: Macro metallographic tests for cross-section examination
- AS 2205.6.1 Methods for destructive testing of welds in metal, Method 6.1: Weld joint hardness test
- AS 2207 Non-destructive testing—Ultrasonic testing of fusion welded joints in carbon and low alloy steel
- AS 3998 Non-destructive testing—Qualification and certification of personnel
- AS/NZS ISO 9001 Quality management systems—Requirements
- AS/NZS ISO 9004 Managing for the sustained success of an organization – A quality management approach

- HB 18.28 Conformity assessment—Guidance on third-party certification system for products
- Safe Work Australia, Code of Practice: Welding processes
- Rail Industry Competency Matrix (National Track and Civil)

NOTE: Documents for informative purposes are listed in a Bibliography at the back of the Standard.

1.3 Terms, definitions and symbols

1.3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in RISSB Glossary: https://www.rissb.com.au/products/glossary/ and the following apply:

a) ***aluminothermic welding***

a welding process in which an aluminothermic reaction takes place within a crucible and the resultant molten metal flows into a weld joint contained by a mould

NOTE: The by-product, aluminium oxide slag, is contained in a side receptacle.

b) ***bond line***

vertical centre-line of a flash butt weld

c) ***closure***

a short length of rail to replace a piece of rail in tracks, also called a plug

NOTE: A minimum length of a closure or plug should be specified by the track owner.

d) ***consumables***

material consumed in the performance of a weld

e) ***flash butt welding***

electrical welding process that produces a weld at the mating surfaces of a butt joint by heating due to high electric current followed by the application of pressure between the two ends of the rail.

f) ***fusion zone***

area of weld metal revealed by etching cut sections

NOTE: This represents the area of molten metal consisting of a mixture of parent metal and weld metal (where applicable) that has solidified to form the weld metal as revealed in the etched cross-section during testing.

g) ***heat-affected zone***

section of the parent rail outside the fusion zone that has mechanical properties altered by the welding process

h) ***heat-softened zone***

part of the heat-affected zone characterized by hardness below that of the parent rail

i) ***job document***

document that describes the specific program of work and refers to the welding procedure to be used

j) ***junction weld***

weld joining together two different rail profiles

NOTES:

1. For example a weld joining a 50 kg and 60 kg rail.
2. See also 'step weld' (Definition l)).

k) ***slope angle***

angle subtended between a horizontal line along the top of the rail surface, and a sloping line along the surface of a rail weld

NOTE: The slope angle is normally measured over a distance of 100 mm along the rail surface and 50 mm either side of the weld centreline.

l) ***step weld***

weld joining together rails of the same profile but of different heights due to wear

Note: see also 'junction weld' (Definition j)).

m) ***upset***

the stage during flash butt welding, after heating, when the two rail ends are forged together. The upset distance is the distance of rail consumed during this process.

n) ***welding procedure***

the written detailed methods and practices involved in the making and testing of a rail weld

o) ***welding procedure qualification record***

the written record of the tests undertaken, and the results obtained, to qualify the welding procedure in accordance with the requirements of this Standard

p) ***visible heat-affected zone***

section of the parent rail either side of the fusion zone within which microstructure has been altered by the heat of the welding process

NOTE: It can be made visible by macro etching and is not to be confused with heat-affected zones identified by hardness variation.

q) ***welding process***

a particular method of welding involving the application of certain metallurgical, electrical, physical, chemical, or mechanical principles.

NOTE: Flash butt, aluminothermic fusion and arc welding are applicable examples.

r) ***weld gap***

the distance between the ends of the rail prior to welding

s) ***weld metal head***

weld metal remaining above the top of the rail profile after solidification

t) ***weld collar***

the thickened area of weld reinforcement surrounding an aluminothermic weld

1.3.2 Notation

The symbols used in this Standard, including their definitions are listed below:

A = a value used in calculating the variation of fatigue results

= $\sum(\mathrm{i}\ \mathrm{n_i})$

AB = distance identified as the width of the heat-softened zone by a hardness traverse just below the rail top surface

AT = Aluminothermic tolerance allowable variation in longitudinal alignment of the welded rail section in the vertical and horizontal directions, when measured using a calibrated measurement device

B = a value used in calculating the variation of fatigue results

= $\sum(\mathrm{i}^2\ \mathrm{n_i})$

D_1, D_2 = collar depth at location A

d = constant stress increment of the staircase, in megapascals, taken as 20 MPa

d_1, d_2 = collar depth at location B

E = eccentricity on the railhead

HBW = Brinell hardness number with the test carried out using tungsten carbide ball

HV H= Vickers hardness number

I = second moment of area of the rail section, in millimetres to the fourth power

i = number assigned to indicate the test stress level (coded stress level) ($i = 0$ for S_0)

L = test span, in millimetres

m = mean fatigue strength, in megapascals

N = total number of less frequent events

= $\sum(\mathrm{n_i})$

n_i = number of less frequent events at the i-th moment level above $\mathrm{S_0}$

P = test load, in newtons

R_f = riser cross-section, at the rail foot

R_N = riser cross-section, at the neutral axis

S_0 = lowest stress range at which tests with the less frequent result were conducted, in megapascals

s = standard deviation

W = weld collar width

X_f = minimum width of fusion zone

X_vhaz = width of visible heat-affected zone, measured at the running surface

y_foot = distance of the extreme fibre in the foot from the neutral axis, in millimetres

σ = outer fibre stress, in megapascals

2 Basic requirements

2.1 General

Welds shall:

(a) be qualified by testing;

(b) be made by appropriately qualified personnel;

(c) be made in accordance with the job document that references the required welding procedure; and

(d) comply with the requirements of this Standard, including testing, for one of the following welding processes:

i. Flash butt welding as given in Sections 3 and 4.

ii. Aluminothermic welding as given in Section 5.

iii. Aluminothermic rail head repair welding as given in Section 6.

iv. Arc rail head welding repairs as given in Section 7.

NOTE: Manufacturers making a statement of compliance with this Australian Standard on product, packaging or promotional material related to that product should ensure that such compliance is capable of being verified.

2.2 Qualification of the welding procedure

2.2.1 Qualification

Welding procedures shall be qualified by testing in accordance with the appropriate Section of this Standard.

The results of all qualification tests carried out shall be recorded in the form of a welding procedure qualification record, together with the relevant welding procedure. This information shall include the welding program used for the qualification testing.

All records shall be kept and made available to those authorized to examine them.

Separate qualification is required for each rail profile and for each rail material grade.

2.2.2 Requalification

Requalification of welding procedures shall be required, and a new welding procedure qualification record produced when:

(a) the rail profile or material grade is changed, including welds at a combination of two different rail grades; or

(b) any aspect of a prequalified procedure has been altered as defined in Sections 3.3, 4.3, 5.3, 6.3 and 7.3 for each welding process, as appropriate, or both.

2.3 Qualification of welding personnel

Welds shall be made by personnel who are qualified according to the requirements of Appendix D.

2.4 Documentation

2.4.1 Job document

The whole of the work to be carried out, including safety precautions, shall be described in a job document. The job document shall make reference to the welding procedure to be used. It shall be readily accessible, held as a record, and available for examination.

NOTES:

1. Rail welding requires considerations other than the production of the weld itself. Some of these will depend on the situation of the weld and the needs of the organizations involved. For example, access to a part of a railway track will require permission from the rail infrastructure manager. The job document should set out how such permission is to be secured and any operating procedures for safety.
2. Safe working procedures that are suitable for the activities to be carried out should be established and included in the job document (see Safe Work Australia, Code of Practice: Welding processes).

2.4.2 Welding procedure

Welding procedures shall be documented, see Sections 3.5, 4.5, 5.5, 6.5 and 7.5. The welding procedure shall be available at the welding site and shall also be referenced in the job document.

2.5 Testing

Test methods for use in this Standard are given in Appendix E to L, and include:

(a) visual inspection alignment and size ranges for imperfections;

(b) non-destructive test;

(c) weld metal hardness;

(d) hardness traverse;

(e) macroscopic test;

(f) microscopic test;

(g) chemical analysis;

(h) slow bend test;

(i) fatigue test.

2.6 Defects

Table 2.1 provides an overview of the type of defects that can occur during the different welding processes described in this Standard.

Table 2.1 – Defect types

Defect type	Description	Applicable welding process	
		Flash butt	Aluminothermic
Cold shut	prematurely chilled regions of metal resulting in unfused discontinuities within the weld metal	✗	✓
Fin	thin projection of weld metal from the weld collar, typically formed as a result of backfilling of cracks in the mould material.	✗	✓
Flashing	thin protrusion of metal extending from the collar of an aluminothermic weld along the joint line between the mould and rail caused by a poor fit between the rail and mould NOTES: 1. This condition can also be referred to as 'cold lap'. 2. "Flashing" can also refer to the period in the flash butt welding process where active sparking is taking place, leading to overall metal loss at the butted surfaces.	✗	✓
Flat spot	A discontinuity present at the bond line of flash butt welds, which can be evident as a circular or elliptical shape but can be large and irregular, and generally have a localized smooth texture in a fracture surface after slow bend testing.	✓	✗
Hot tear	fracture in the weld caused by excessive tension during solidification of the molten weld metal	✓*	✓
Inclusions	Non-metallic matter entrapped during welding.	✓	✓
Lack of bond	Area of incomplete fusion between the rails in flash butt welds, which may also appear as small scale cracks or voids NOTE: Lack of bond is also referred to as 'lack of fusion'.	✓	✓
Porosity	Cavities formed by entrapped gas during the solidification of molten metal	✗	✓
Short head	Insufficient weld metal to adequately fill the head, due to leakage elsewhere in the mould. (See definition s))	✗	✓
Shrinkage crack	Local cavity in the weld metal occurring during solidification. It can be on the surface or in the body of the weld.	✓	✓

Legend
✓ applies to the process
✗ does not apply to the process
✓ can be an issue in exceptional circumstances.*

3 Fixed plant flash butt welding

3.1 General

This section covers the joining of lengths of rail by flash butt welding at permanent installations. This section does not cover mobile machines used at a fixed location.

3.2 Description of the process

Flash butt welding is a resistance welding process that produces a weld at the mating surfaces of a butt joint by a flashing action and by the application of pressure after heating is substantially completed. The flashing action, caused by very high current densities at small contact points between the workpieces, forcibly expels the material from the joint as the workpieces are slowly moved together. The weld is completed by a rapid upsetting of the workpieces. Excess material resulting from the upset stage is then removed by shearing.

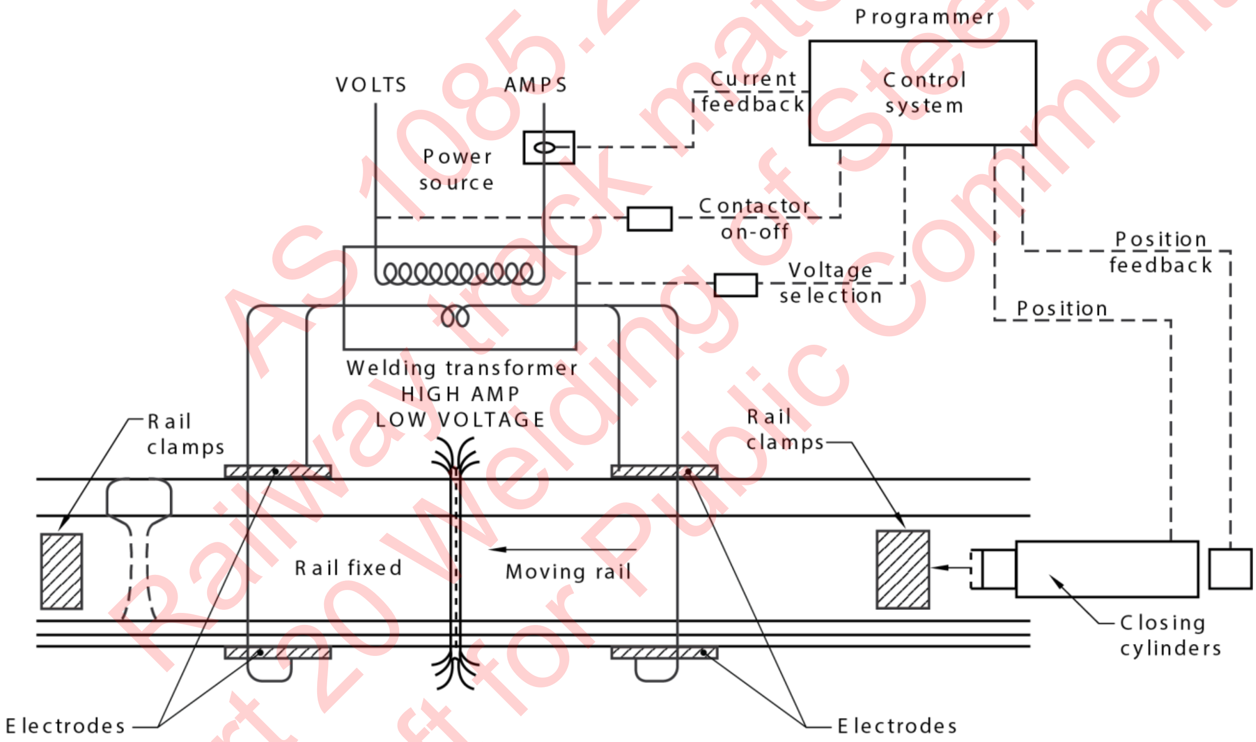


Figure 3.1 Typical fixed plant flash butt welding set-up

3.3 Qualifying flash butt welding set-up

A flash butt welding procedure shall be qualified in accordance with appendix M.

Qualification shall be undertaken prior to the commencement of production welding for fixed plant welding equipment manufacturing long welded rail. This shall be performed on an annual basis, and/or if the flash butt welding equipment has not been used for more than six months.

Test welds prepared for qualification according to this Standard shall be manufactured in new rail.

Requalification of a flash butt welding procedure shall be carried out when either:

(a) any change in any of the welding parameters (cycle time, duration of flashing, voltage, amps, and similar) exceeds 10 %, or

(b) the preheating is changed.

Following initial qualification of a flash butt welding procedure and commencement of production welding, regular testing shall be carried out in accordance with clause 3.7. Additional tests may be undertaken in accordance with a quality assurance plan as agreed between the contracting parties. A set of three routine slow bend tests are recommended every 1,000 welds for fixed plant flash butt welder.

In addition to the requirements outlined above, additional slow bend testing (see Appendix K) shall be undertaken for fixed welding equipment following rectification of a welding machine malfunction, and following equipment overhaul that could affect the welder's functionality, such as part replacements.

3.4 Job document

All flash butt welds shall have a job document prepared, which shall include the following:

(a) Description of the work.

(b) A reference to the qualified welding procedure to be used.

(c) An arrangement for the protection of the equipment and the welded rail from adverse weather conditions during the process of welding and subsequent cooling.

(d) Workplace health and safety (WHS) requirements.

(e) Any preparatory tasks needed prior to welding (e.g. permission for access).

3.5 Welding procedure

This welding procedure shall include as a minimum:

(a) Name of the procedure.

(b) Welding personnel qualification, welding shall be performed by personnel qualified to the requirements of appendix D.

(c) Rail type, rail type shall be described (e.g. 60 kg head-hardened).

(d) Diagrams of the process.

(e) List of equipment.

(f) The method used for removing the scale and rust at the ends to be welded as well as the electrical contact surfaces (typically head and foot of the rail for fixed welders). This method should ensure that these surfaces remove the oxide back to bare metal. The method used for qualification welds should be the same as that used for production welding.

(g) Alignment of rails, rails shall be aligned prior to welding, taking into account cooling and the specified tolerance of the finished weld. Alignment is required both vertically and horizontally.

(h) Preheating (If applicable).

(i) Welding parameters, which shall include identification of critical parameters of flash butt welding equipment. These include the preheating conditions, recording of flashing to ensure that this is not interrupted, upset load, current and upset (forging) distance. The record shall be available as a chart which includes the overall during of the welding cycle as well as recording when the shearing process was performed.

(j) Post-weld heat treatment (If applicable).

(k) Controlled cooling (If applicable).

NOTE: Cooling of the weld will need to be controlled to achieve the mechanical and microstructural properties.

(l) Pressing of weld for alignment.

(m) Dressing and grinding of welds: After welding, excess metal shall be removed and the running surface and both sides of the head finished by grinding. Final grinding shall be conducted in such a way that the temperature of the rail is not high enough to cause any metallurgical change.

NOTE: Additional grinding can be required of the other sheared surfaces such as the web, underside of the rail head or foot or the outer edges of the foot as specified by the Purchaser.

(n) Inspection and testing, post-weld inspection and testing shall be carried out as given in Section 0.

(o) Marking and records, marking and records shall be in accordance with Section 3.8.

NOTES:
1. The ends of the welded string may be drilled with consideration given to the number and position of holes. Generally, holes are not allowed closer to the end than the position of the second hole in the 6-hole fishplate for that rail.

2. Monitoring of the machine parameters (such as flashing time, current, hydraulic pressure, upset slippage and similar) can assist in control of the quality of the welds.

3. A finished weld should be selected from normal production on a regular basis and tested in accordance with Appendix M, to ensure the welds continue to comply with this Standard.

(p) Qualification to AS 1085.20 statement that the procedure has been qualified to this standard.

3.6 Maintenance of equipment

The equipment shall be maintained and calibrated in accordance with a written procedure.

3.7 Inspection and testing of finished welds

Inspection and testing of all finished welds shall be carried out to ensure the weld satisfies the criteria given in Table 3.1 for weld collar tolerances, surface alignment (AT1, AT2 and AT3, as specified) and non-destructive testing.

Table 3.1 Inspection of finished flash butt welds

Test	Test Method (appendix)	Description	Pass criteria		
Visual inspection	E	Visual inspection of all surfaces	No cracks, tears, gouges, shear drag, electrical contact burns, grinding burns		
Surface alignment tolerances	E	Alignment tolerance grade (Note 1,3)	Vertical	Horizontal	Maximum slope angle on top of rail
		AT1	0.0 mm, +0.3 mm	±0.5 mm	±7 milliradians (Note 2)
		AT2	0.0 mm, +0.5 mm	±0.5 mm	Limit to be specified by the purchaser
		AT3	Limit to be specified by the purchaser	Limit to be specified by the purchaser	Limit to be specified by the purchaser
Weld collar tolerances – Deviation from rail profile	E	At rail web and upper side of rail foot	0.0 mm, + 2.0 mm		
		Underside of rail foot	0.0 mm, +1.0 mm		
		The maximum grinding deviation with respect to rail surface profile:			
		Top of railhead	-0.0 mm, +0.15 mm		
		Side of railhead	-0.0 mm, +0.3 mm		
Non-destructive test	F	Internal imperfections	Railway owners should determine the limits for internal imperfections. Suitable values are given in Appendix F.		
		Magnetic particle inspection	2 mm maximum linear indication		

NOTES:

1. The grade is specified for the application. Selection of tolerance level will affect the loads experienced at the weld and thus the expected life of the joint for given track conditions and level of traffic.
2. Measured over a distance of 100 mm along the rail surface and 50 mm either side of the weld centre-line (section 1.3.1,definition 9l)).
3. An AT1 tolerance grade would be applicable for a high speed passenger line. An AT2 tolerance grade would be generally applicable for main lines

3.8 Marking and records

3.8.1 Marking

Unique markings shall be incorporated onto the rail web of each weld. The marking shall be in letters of not less than 10 mm high and shall remain legible for a minimum period of 12 months from the date on which the weld was made.

3.8.2 Records

A record of the procedure shall be kept, which shall include manufacturer's identification, weld number, date, rail string classification type and post-welding treatments applicable to the weld, the rail number, welding parameters, (e.g. primary welding current, upset force, welding cycle time), inspection and testing.

Records should also be kept of the program used to make the welds during qualification trials so that it can be uniquely linked to that used for production welds.

3.8.3 Monitoring

Key parameters, as well as measurement of the overall heat input (i.e. combination of current and voltage input over the welding cycle), should be regularly monitored. These can indicate issues with rail surface preparation, current straps, machine cleanliness, cooling systems issues, etc.

4 Mobile flash butt welding

4.1 General

This section covers the joining of lengths of rail by flash butt welding using portable equipment at a fixed location, in the field or on track. Other processes using induction heating may be used if the welds produced can meet all the requirements identified in this section.

4.2 Description of the process

Flash butt welding is a resistance welding process that produces a weld at the mating surfaces of a butt joint by a flashing action and by the application of pressure after heating is substantially completed. The flashing action, caused by very high current densities at small contact points between the workpieces, forcibly expels the material from the joint as the workpieces are slowly moved together. The weld is completed by a rapid upsetting of the workpieces. Excess material resulting from the upset stage is then removed by shearing.

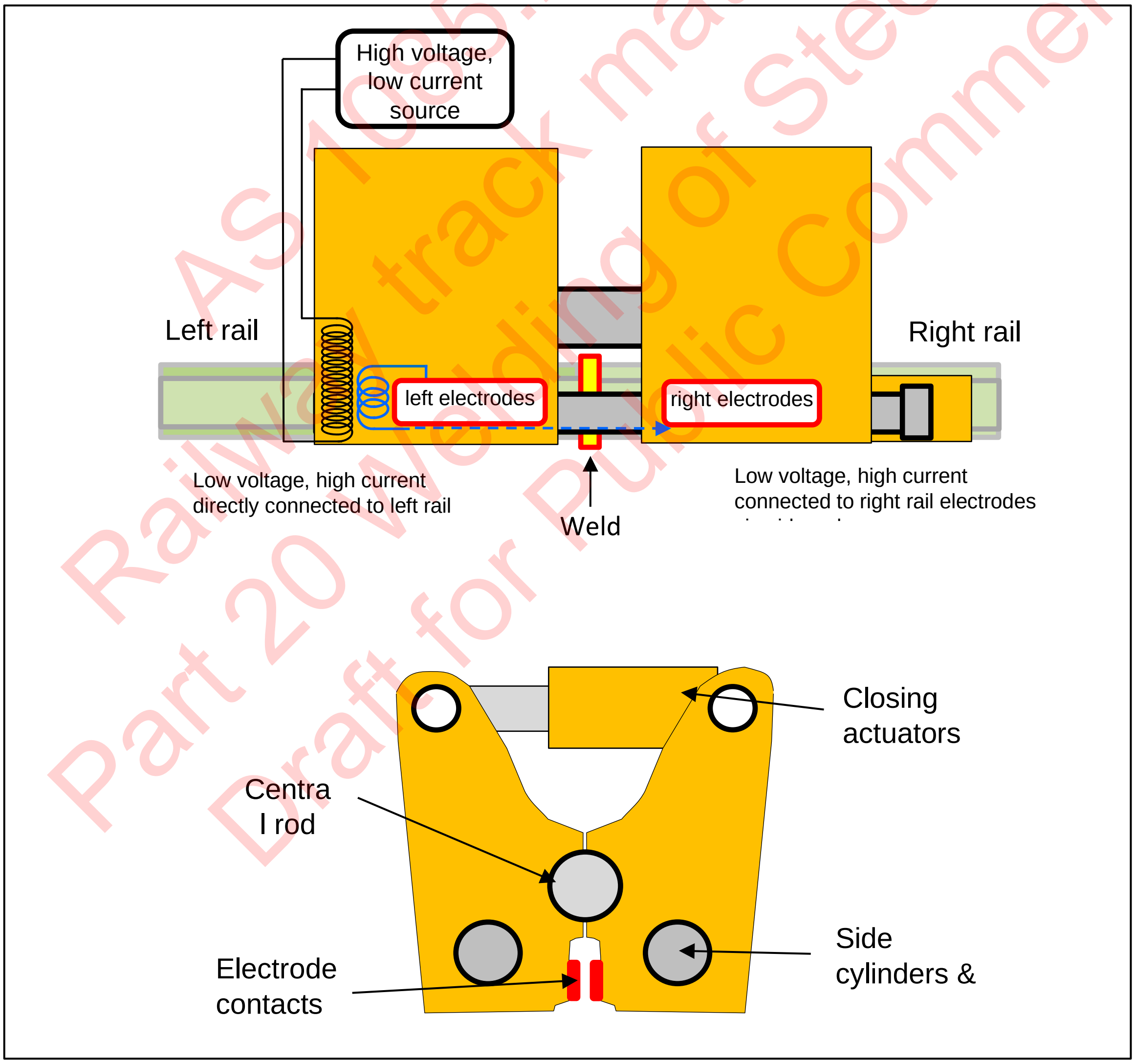


Figure 4.1 Typical flash butt welding set-up

4.3 Qualifying flash butt welding set-up

A flash butt welding procedure shall be qualified in accordance with appendix M.

Qualification shall be undertaken prior to the commencement of production welding for mobile welding equipment operated as fixed plant for the manufacture of long welded rail or used in the field.

Subsequent requalification shall be carried out annually, unless otherwise specified by the rail infrastructure manager.

Test welds prepared for qualification according to this Standard shall be manufactured in new rail. Note that welding used rails in track can introduce variations to the process, such that additional qualification tests will be required if rails have high head loss or different rail grades.

Requalification of a flash butt welding procedure shall be carried out when either:

(a) any change in any of the welding program parameters that will significantly change the heat input into the weld, or

(b) affect the hydraulic or mechanical system.

Following initial qualification of a flash butt welding procedure and commencement of production welding, regular testing shall be carried out in accordance with clause 4.7. Additional tests may be undertaken in accordance with a quality assurance plan as agreed between the contracting parties. A set of three routine slow bend tests shall be performed every 500 welds for a mobile plant flash butt welder operating at a fixed location, or every three months for a mobile welder operating in the field.

In addition to the requirements outlined above, additional slow bend testing (see Appendix K) shall be undertaken for mobile welding equipment following rectification of a welding machine malfunction, and following equipment overhaul that could affect the welder's functionality, such as part replacements.

4.4 Job document

All flash butt welds shall have a job document prepared, which shall include the following:

(a) Description of the work.

(b) A reference to the qualified welding procedure to be used.

(c) An arrangement for the protection of the equipment and the welded rail from adverse weather conditions during the process of welding and subsequent cooling.

(d) Workplace health and safety (WHS) requirements.

(e) Any preparatory tasks needed prior to welding (e.g. permission for access).

(f) The use of rail tensioning equipment, where required.

4.5 Welding procedure

This welding procedure shall include as a minimum:

(a) Name of the procedure.

(b) Welding personnel qualification, welding shall be performed by personnel qualified to the requirements of Appendix D.

(c) Rail type: rail type shall be described (e.g. 60 kg head-hardened).

(d) Overall rail head loss, and mismatch in rail head loss from one rail to the other.

(e) Diagrams of the process.

(f) List of equipment.

(g) Weather conditions, limits on weather conditions where welding is to be carried out in the open.

(h) Proximity of boltholes and other welds, the welding procedure shall define the proximity of boltholes and the minimum distance to other flash butt or aluminothermic welds.

(i) End and web preparation: The grinding methods used for removing the scale and rust at the ends to be welded as well as the electrical contact surfaces used to prepare the web for the electrodes shall be documented. The web grinding needs to remove any raised brand in the rail, and include the entire area where the electrodes will make contact. The preparation method used for qualification welds should be the same as that used for production welding.

(j) Alignment of rails: Rails shall be aligned prior to welding, taking into account cooling and the specified tolerance of the finished weld. Correct alignment is required both vertically and horizontally.

(k) Track lifting procedure for track lifting and removal of plastic components (e.g. rail pads). (For in-track welding only.)

(l) Welding parameters, which shall include identification of critical parameters of flash butt welding equipment. These include the preheating conditions, recording of flashing to ensure that this is continuous, upset load, current, and upset (forging) distance. The record shall be available as a chart which includes the overall during of the welding cycle as well as recording when the shearing process was performed.

(m) Post-weld heat treatment (If applicable).

(n) Controlled cooling (If applicable).

NOTE: Cooling of the weld will need to be controlled to achieve the mechanical and microstructural properties.

(o) Dressing and grinding of welds: After welding, excess metal shall be removed and the running surface and both sides of the head finished by grinding. Final grinding shall be conducted in such a way that the temperature of the rail is not high enough to cause any metallurgical change. A hand held grinder shall not be used on the running surface or side of the rail.

NOTE: Additional grinding can be required of the other sheared surfaces such as the web, underside of the rail head or foot or the outer edges of the foot.

(p) Inspection and testing, post-weld inspection and testing shall be carried out as given in clause 4.7.

(q) Marking and records, marking and records shall be in accordance with clause 4.8.

NOTES:

1. The ends of the welded string may be drilled with consideration given to the number and position of holes. Generally, holes are not allowed closer to the end than the position of the second hole in the 6-hole fishplate for that rail.
2. Monitoring of the machine parameters (such as flashing time, current, hydraulic pressure, upset slippage and similar) will assist in control of the quality of the welds.
3. It is recommended that a finished weld be selected from normal production on a regular basis and tested in accordance with Appendix M, to ensure the welds continue to comply with this Standard.

(r) Qualification to AS 1085.20 statement that the procedure has been qualified to this standard.

4.6 Maintenance of equipment

The equipment shall be maintained and calibrated in accordance with a written procedure.

4.7 Inspection and testing of finished welds

Inspection and testing of all finished welds shall be carried out to ensure the weld satisfies the criteria given in Table 4.1 for weld collar tolerances, surface alignment (AT1, AT2 and AT3, as specified) and non-destructive testing.

Table 4.1 Inspection of finished flash butt welds

Test	Test Method (appendix)	Description	Pass criteria		
Visual inspection	E	Visual inspection of all surfaces	No cracks, tears, gouges, shear drag, electrical contact burns, grinding burns		
Surface alignment tolerances	E	Alignment tolerance grade (Note 1)	Vertical	Horizontal	Maximum slope angle on top of rail
		AT1	0.0 mm, +0.3 mm	±0.5 mm	±7 milliradians (Note 2)
		AT2	0.0 mm, +0.5 mm	±0.5 mm	Limit to be specified by the purchaser
		AT3	Limit to be specified by the purchaser	Limit to be specified by the purchaser	Limit to be specified by the purchaser
Weld collar tolerances – Deviation from rail profile	E	At rail web and upper side of rail foot	0.0 mm, + 2.0 mm		
		Underside of rail foot	0.0 mm, +2.0 mm		
		The maximum grinding deviation with respect to rail surface profile:			
		Top of railhead	-0.0 mm, +0.15 mm		
		Side of railhead	-0.0 mm, +0.3 mm		

Test	Test Method (appendix)	Description	Pass criteria
Non-destructive test	F	Internal imperfections	Railway owners should determine the limits for internal imperfections. Suitable values are given in Appendix F.
		Magnetic particle inspection	2 mm maximum linear indication

NOTES:

1. The grade is specified for the application. Selection of tolerance level will affect the loads experienced at the weld and thus the expected life of the joint for given track conditions and level of traffic.
2. Measured over a distance of 100 mm along the rail surface and 50 mm either side of the weld centre-line (see section, 1.3.1, definition 9k)).
3. An AT1 tolerance grade would be applicable for a high speed passenger line. An AT2 tolerance grade would be generally applicable for main lines.

4.8 Marking and records

4.8.1 Marking

Unique markings shall be incorporated onto the rail web of each weld. The marking shall be in letters of not less than 10 mm high and shall remain legible for a minimum period of 12 months from the date on which the weld was made.

4.8.2 Records

A record of the procedure shall be kept, which shall include manufacturer's identification, weld number, date, rail string classification type and post-welding treatments applicable to the weld, the rail number, welding parameters, (e.g. primary welding current, upset force, welding cycle time), inspection and testing.

Records should also be kept of the program used to make the welds during qualification trials so that it can be uniquely linked to that used for production welds.

4.8.3 Monitoring

Key parameters, as well as measurement of the overall heat input (i.e. combination of current and voltage input over the welding cycle), should be regularly monitored. These can indicate issues with rail surface preparation, current straps, machine cleanliness, cooling systems issues, etc.

5 Aluminothermic welding

5.1 General

This section covers the joining of lengths of rail by aluminothermic welding. Aluminothermic welding is usually carried out on the track.

NOTE: Use of aluminothermic welding for head repair welds is covered in section 6.

5.2 Description of process

Aluminothermic welding is a process in which an aluminothermic reaction takes place within a crucible, from the following chemical reaction between iron oxide and aluminium:

$Fe2O3 + 2Al \rightarrow 2Fe + Al2O3 + Heat$

The resultant molten metal flows into a weld joint contained by a mould and the rail ends. The joint is formed by the fusion of the weld metal and the rail.

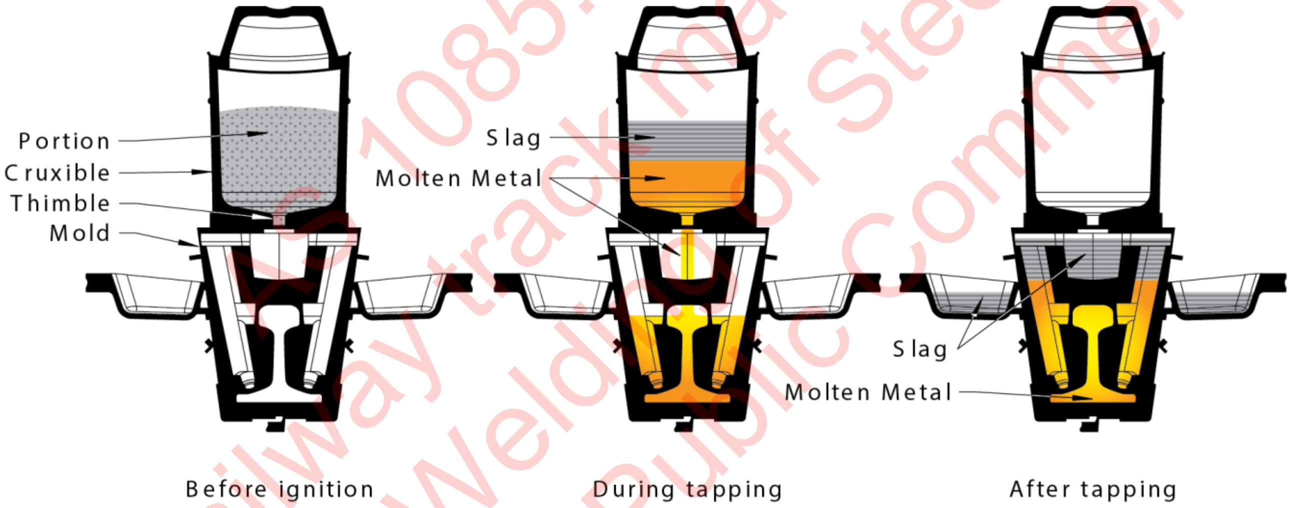


Figure 5-1 Typical aluminothermic welding process

NOTES:

1. Crucibles can be either single use or reusable.
2. Single use crucible illustrated above

5.3 Qualifying the welding procedure

An aluminothermic welding procedure shall be qualified in accordance with appendix N.

Test welds prepared for qualification according to this standard shall be manufactured in new rail.

Requalification of aluminothermic welding shall be carried out when a change in the welding parameters exceeds the range set out in paragraph N4, appendix N.

Following initial qualification of an aluminothermic welding procedure, testing of individual batches of consumables shall be carried out on a regular basis for quality control purposes.

5.4 Job document

All aluminothermic welds shall have a job document prepared, which shall include the following:

(a) description of the work;

(b) selection of the welding process, taking into account the following:

i. type and size of rail;

ii. weld of same profile or junction or step weld;

iii. size of gap;

iv. speed of process (quick or slow, i.e. short or long pre-heat);

v. control of fume (for enclosed spaces);

vi. the impact of the weld on rail adjustment in the area;

(c) a reference to the qualified welding procedure to be used;

(d) an arrangement for the protection of the equipment and the welded rail from adverse weather conditions during the process of welding and subsequent cooling;

(e) workplace health and safety (WHS) requirements;

(f) storage and transport of materials;

(g) any preparatory tasks needed prior to welding (e.g. permission for access);

(h) the use of rail tensioning equipment, where required;

(i) time or temperature at which traffic can be allowed to pass;

(j) maximum time before inspection and testing is carried out.

5.5 Welding procedure

This welding procedure shall include as a minimum:

(a) Name of the procedure.

(b) Welding personnel qualification, welding shall be performed by personnel qualified to the requirements of appendix D.

(c) Rail type.

(d) Manufacturer's instructions, the procedure shall include relevant information provided by the manufacturer of the consumables, including diagrams.

(e) List of equipment.

(f) Weather conditions, limits on weather conditions where welding is to be carried out in the open.

NOTE: Unless special controls and approvals are in place, welding should not be performed:

1. where fire restrictions are in place;
2. in extreme temperatures;
3. during high winds; and
4. during heavy rain.

(g) Proximity of boltholes and other welds: The welding procedure shall state the proximity of boltholes, the distance to other flash butt or aluminothermic welds and, for closure welds, the minimum time between adjacent welds in the same rail.

(h) Rail end preparation: The welding procedure shall define the procedure for cutting of the rail and tolerances for the squareness and surface finish of the cut ends.

(i) Track lifting procedure for track lifting and removal of plastic components (e.g. rail pads).

(j) Alignment of rails, rails shall be aligned prior to welding, taking into account cooling and the specified tolerance of the finished weld. Alignment is required both vertically and horizontally.

(k) Preheating fuel type and pressure, oxygen pressure, and duration as prescribed by the manufacturer.

(l) Welding parameters: Welding parameters shall include identification of critical parameters of aluminothermic welding equipment.

(m) Post-weld heat treatment (If applicable).

(n) Mould removal process timings from end of reaction to start of mould removal, including (i) removal of crucible, (ii) stripping of the mould, and (iii) commencement of shearing.

(o) Dressing and grinding of welds after welding, excess metal shall be removed, and the running surface finished by grinding. All grinding shall be conducted in such a way that the temperature of the rail is not high enough to cause any metallurgical changes and the finished surface is free of sharp edges. A hand held grinder shall not be used on the running surface or side of the rail.

(p) Inspection and testing post-weld inspection and testing shall be carried out as given in Section 5.7.

(q) Marking and records marking and records shall be in accordance with Section 5.8.

(r) Qualification to AS 1085.20, statement that the procedure has been qualified to this standard.

5.6 Maintenance of equipment

The equipment shall be maintained and calibrated in accordance with a written procedure.

5.7 Inspection and testing of finished welds

Inspection and testing of all finished welds shall be carried out to ensure the weld satisfies the requirements given in Table 5.1 for surface finish, surface alignment (AT1, AT2 and AT3, as specified) and non-destructive testing.

Table 5.1 Test limits for finished aluminothermic welding

Test	Test method (appendix)	Description	Pass criteria
Surface finish tolerances	E	Visual inspection of all surfaces	Satisfactory external appearance and shape; no gouges, cracks, tears, porosity, weld protrusion, shear drag or evidence of a short head.

Test	Test method (appendix)	Description	Pass criteria		
Surface alignment	E	Alignment tolerance grade (Note 1)	Vertical	Horizontal	Maximum slope angle on top of rail
		AT1	0.0 mm, +0.3 mm	±0.5 mm	±7 milliradians (Note 2)
		AT2	0.0 mm, +0.5 mm	±0.5m mm	Limit to be specified by purchaser
		AT3	Limit to be specified by purchaser	Limit to be specified by purchaser	Limit to be specified by purchaser
Non-destructive test	F	Internal imperfections	Railway owners should determine the limits for internal imperfections. Suitable values are given in Appendix F. See note 4.		
		Magnetic particle inspection	2 mm maximum linear indication		

NOTES:

1. The grade is specified for the application. Selection of tolerance level will affect the loads experienced at the weld and thus the expected life of the joint for given track conditions and level of traffic.
2. Measured over a distance of 100 mm along the rail surface and 50 mm either side of the weld centre-line. (definition 1.4.30).
3. An AT1 tolerance grade would be applicable for a high speed passenger line. An AT2 tolerance grade would be generally applicable for main lines.
4. MPI should only be carried out on the top and side of the head, after grinding.

5.8 Marking and records

5.8.1 Marking

Unique markings shall be incorporated onto the rail web of each weld. The marking shall be in letters of not less than 10 mm high and shall remain legible for a minimum period of 12 months from the date on which the weld was made.

5.8.2 Records

A record of the procedure (weld return) shall be kept, which shall include the weld number, date, location, welding information (e.g. preheat time, weld gap, tapping time, time to first train), identification of the welder, inspection and testing, consumable manufacturer, process type and batch number.

6 Aluminothermic rail head repair welding

6.1 General

This section covers the repair of head defects in rail by aluminothermic head repair welding.

Aluminothermic rail head repair welding is usually carried out on the track.

NOTE: Use of aluminothermic welding for joining rails is covered in section 3 of this document.

6.2 Description of process

Aluminothermic welding is a process in which an aluminothermic reaction takes place within a crucible, from the following chemical reaction between iron oxide and aluminium;

$Fe2O3 + 2Al \rightarrow 2Fe + Al2O3 + Heat$

and the resultant molten metal flows into a weld joint contained by a mould and the rail head. See Figure 6-1.

In head repair welding the defect is first mapped ultrasonically to ensure that it fits within the confines of the mould. The defect is then removed by an appropriate method. The refractory moulds are then fitted around the ground area and sealed. The rail head is preheated and then the aluminothermic reaction initiated to produce molten steel which pours into the mould fusing to the rail, replacing the removed metal

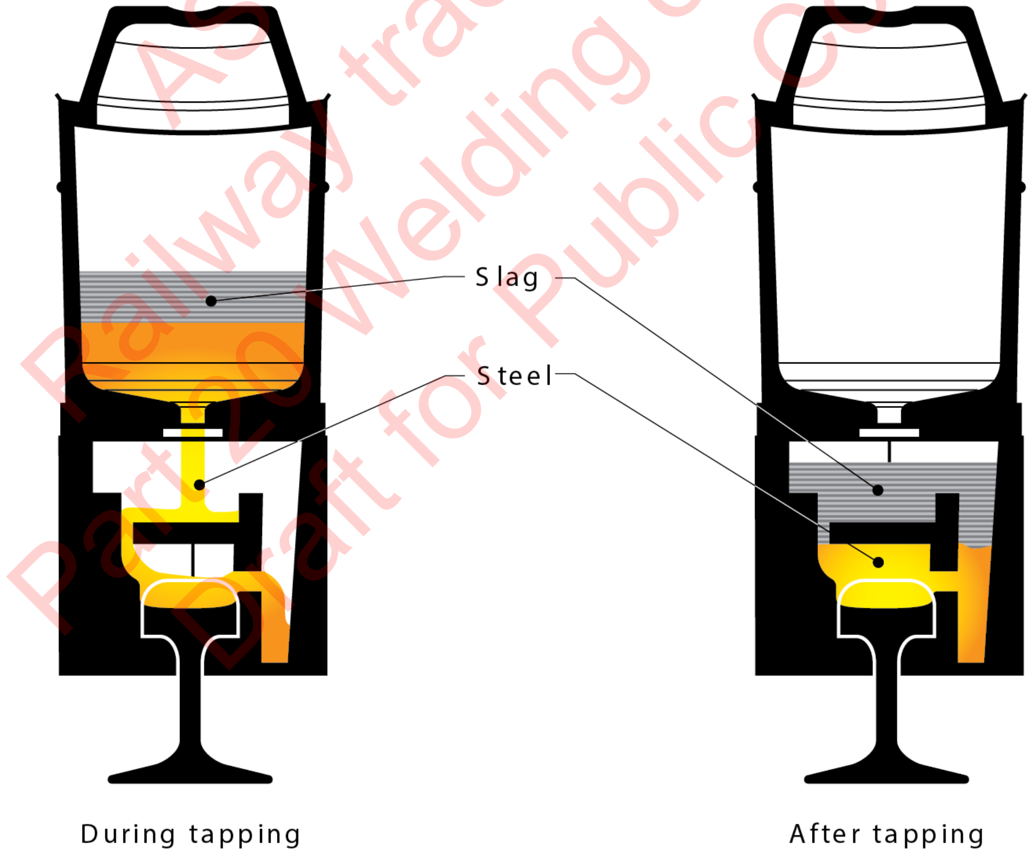


Figure 6.1 Typical aluminothermic head repair welding process

6.3 Qualifying the welding procedure

An aluminothermic head repair welding procedure shall be qualified in accordance with appendix N.

Requalification of aluminothermic head repair welding shall be carried out when a change in the welding parameters exceeds the range set out in paragraph N4, Appendix N.

6.4 Job document

All aluminothermic head repair welds shall have a job document prepared, which shall include the following:

(a) Description of the work to be performed including the portion of the railhead to be repaired;

(b) Selection of the head repair welding process, taking into account the following:

  i. type and size of rail.

  ii. speed of process (quick or slow, that is, short or long pre-heat).

  iii. control of fume (for enclosed spaces).

(c) A reference to the qualified welding procedure to be used.

(d) An arrangement for the protection of the equipment and the welded rail from adverse weather conditions during the process of welding and subsequent cooling.

(e) Workplace health and safety (WHS) requirements.

(f) Storage and transport of materials.

(g) Any preparatory tasks needed prior to welding (e.g. permission for access).

(h) Time or temperature at which traffic can be allowed to pass.

(i) Maximum time before inspection and testing is carried out.

6.5 Welding procedure

This welding procedure shall include as a minimum:

(a) Name of the procedure.

(b) Welding personnel qualification welding shall be performed by personnel qualified the requirements of appendix D.

(c) Rail type.

(d) Manufacturer's instructions - the procedure shall include relevant information provided by the manufacturer of the consumables, including diagrams.

(e) List of equipment.

(f) Weather conditions - limits on weather conditions where welding is to be carried out in the open.

NOTE: Unless special controls and approvals are in place welding should not be performed:

1. Where fire restrictions are in place.
2. In extreme temperatures.

3. During high winds; and
4. In heavy rain.

(g) Proximity of boltholes and other welds - the welding procedure shall define the allowable proximity of boltholes and the distance to other flash butt or aluminothermic welds.

NOTE: Head repairs should not be made above existing aluminothermic welds where train axle loads are equal to or greater than 20 tonnes.

(h) Preparation of head defect to be welded: The welding procedure shall include the procedure for the removal of the rail defect, the required surface condition of the dressed defect removal area, and the maximum allowable depth of defect that can be repaired using this method.

(i) *Non-destructive testing*: Magnetic particle/dye penetrant tests shall be performed to check extent of cracking before and after grinding. All cracks shall be removed before welding commences.

(j) *track lifting*: a procedure shall be specified for peaking of the rail in the area where the defect is being removed and any required removal of plastic components (e.g. rail pads).

(k) *alignment of rails:* rails shall be aligned prior to welding, taking into account cooling and the specified tolerance of the finished weld. Alignment is required both vertically and horizontally.

(l) *Preheating:* fuel type and pressure, oxygen pressure, and duration as prescribed by the manufacturer.

(m) *welding parameters*: welding parameters shall include identification of critical parameters of aluminothermic welding equipment.

(n) post-weld heat treatment (If applicable).

(o) *mould removal process:* process timings from end of reaction to start of mould removal, including (i) removal of crucible, (ii) stripping of the mould, and (iii) commencement of shearing.

(p) dressing and grinding of head repair weld after welding, excess metal shall be removed, and the running surface finished by grinding. All grinding shall be conducted in such a way that the temperature of the rail is not high enough to cause any changes in the metallurgical structure of the rail and the finished surface is free of sharp edges. A hand held grinder shall not be used on the running surface or side of the rail.

(q) inspection and testing, post-weld inspection and testing shall be carried out as given in Section 7.7.

(r) marking and records, marking and records shall be in accordance with Section 7.8.

(s) qualification to AS 1085.20 statement that the procedure has been qualified to this standard.

6.6 Maintenance of equipment

The equipment shall be maintained and calibrated in accordance with a written procedure.

6.7 Inspection and testing of finished welds

Inspection and testing of all finished head repair welds shall be carried out to ensure the weld satisfies the requirements given in Table 6.1 for surface finish, surface alignment (AT1, AT2 and AT3, as specified) and non-destructive testing.

Table 6.1 Test limits for finished aluminothermic head repair welds

Test	Test method (appendix)	Description	Pass criteria		
Surface finish tolerances	E	Visual inspection of all surfaces	Satisfactory external appearance and shape; no gouges, cracks, tears, porosity, weld protrusion, shear drag or evidence of a short head		
Surface alignment tolerances	E	Alignment tolerance grade * (Note 1)	Vertical	Horizontal	Maximum slope angle on top of rail
		AT1	0.0 mm ±0.3 mm	±0.5 mm	±7 milliradians (Note 2)
		AT2	0.0 mm +0.5 mm	±0.5 mm	Limit to be specified by the purchaser
		AT3	Limit to be specified by the purchaser	Limit to be specified by the purchaser	Limit to be specified by the purchaser
Non-destructive test	F	Internal imperfections	Railway owners should determine the limits for internal imperfections. Suitable values are given in Appendix F. See note 4.		
		Magnetic particle inspection	2 mm maximum linear indication		

NOTES:

1. The grade is specified for the application. Selection of tolerance level will affect the loads experienced at the weld and thus the expected life of the joint for given track conditions and level of traffic.
2. Measured over a distance of 100 mm along the rail surface and 50 mm either side of the weld centre-line (see section 1.3.1, definition k)).
3. An AT1 tolerance grade would be applicable for a high speed passenger line. An AT2 tolerance grade would be generally applicable for main lines.
4. MPI should only be carried out on the top and side of the head, after grinding.

6.8 Marking and records

6.8.1 Marking

Unique markings shall be incorporated onto the rail web of each weld. The marking shall be in letters of not less than 10 mm high and shall remain legible for a minimum period of 12 months from the date on which the weld was made.

6.8.2 Records

A record of the procedure (weld report) shall be kept, which shall include the weld number, date, location, welding information (e.g. pre-heat time, weld gap, tapping time, time to first train), identification of the welder, inspection and testing, consumable manufacturer, process type and batch number.

7 Electric arc rail head repair welding

7.1 General

This section covers the repair of head defects in rail by electric arc welding. The methods described may be used for the repair of wheel burns and switch and crossing (S&C) components such as switch blades and wing rails.

NOTE: It is not intended to cover the joining of rails by arc welding.

7.2 Descriptions of welding methods

7.2.1 Manual metal arc welding (MMAW)

Manual metal arc welding is a process of arc welding with a covered electrode manually applied by the welder, without automatic or semi-automatic replacement of the electrode. Shielding is provided only by decomposition of the electrode covering.

7.2.2 Flux-cored arc welding (FCAW)

Flux-cored arc welding is a process that uses a consumable continuous flux cored electrode, which provides the filler metal. Shielding is provided by the flux contained within the electrode. Additional shielding can be obtained from an externally supplied gas or gas mixture.

7.2.3 Metal inert gas welding (MIG)

Metal inert gas welding is a process of arc welding with a bare wire electrode with shielding provided from an externally supplied gas or gas mixture. This process is unsuitable for welding on track due to wind disturbing the shielding gas, but may be used indoors where air movement is not an issue.

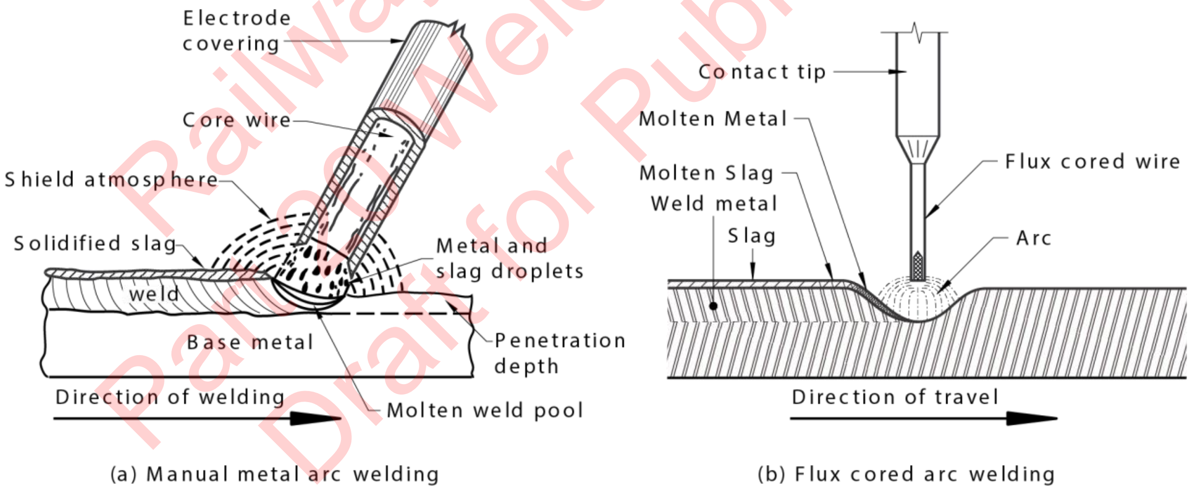


Figure7.1 Electric arc welding processes

7.3 Qualifying the welding procedure

An arc welding procedure shall be qualified in accordance with Appendix O.

Requalification of an arc welding procedure shall be carried out when a change in the welding parameters exceeds the range set out in Appendix O.

7.4 Job document

All arc welds shall have a job document prepared, which shall include the following:

(a) Description of the work to be performed including the portion of the railhead to be repaired;

(b) A reference to the qualified welding procedure to be used;

(c) An arrangement for the protection of the equipment and the welded rail from adverse weather conditions during the process of welding and subsequent cooling;

(d) Workplace health and safety (WHS) requirements;

(e) Any preparatory tasks needed prior to welding (e.g. permission for access);

(f) Maximum time before inspection and testing is carried out.

7.5 Welding procedure

This welding procedure shall include as a minimum:

(a) Name of the procedure.

(b) Welding personnel qualification: Welding shall be performed by personnel qualified to the requirements of Appendix D.

(c) Rail type.

(d) Manufacturer's instructions: The procedure shall include relevant information provided by the manufacturer of the consumables, including diagrams. Note that alternate procedures may be used if approved by the purchaser.

(e) List of equipment.

(f) Weather conditions, limits on weather conditions where welding is to be carried out in the open.

NOTE: Unless special controls and approvals are in place welding should not be performed:

1. Where fire restrictions are in place.
2. In extreme temperatures.
3. During high winds; and
4. In heavy rain.

(g) Proximity of other welds, the welding procedure shall define the allowable distance to other flash butt or aluminothermic welds.

NOTE: Head repairs should not be carried out above existing aluminothermic welds where train axle loads are equal to or greater than 20 tonnes. A minimum distance of 100 mm is advised from aluminothermic welds.

(h) Preliminary non-destructive testing, prior to carrying out any work, testing shall be carried out to check for the presence of cracking or other defects in the rail.

(i) Grinding, defects shall be removed by grinding.

NOTE: The maximum build-up should be defined by the person writing the welding procedure.

(j) Non-destructive testing, magnetic particle/dye penetrant tests shall be performed to check extent of cracking before and after grinding.
All cracks shall be removed before welding commences.

(k) Plastic components, a procedure that shall be used to remove from the track plastic components that are likely to be affected by the welding (e.g. rail pads).

(l) Preheating, the repair area plus a minimum 100 mm on either side of the repair shall be preheated.

(m) Welding parameters, procedures shall define the welding parameters, e.g. amperages, volts, travel speed, electrode stick out, and similar, including identification of critical parameters.

(n) Welding techniques, weld beads should be made primarily in the longitudinal direction using a weaving pattern that is wide to start and narrows down to a stringer at the end, or in a pattern similar to that shown in Figure7.2. Arc strike shall not be permitted outside the preheated weld area.

(o) Interpass temperature, the procedure shall define the minimum rail temperature to maintain throughout the welding of the rail.

(p) Post-weld heat treatment (If applicable).

(q) Dressing and grinding of welds, after welding, excess metal shall be removed, and the running surface finished by grinding. All grinding shall be conducted in such a way that the temperature of the rail is not high enough to cause any metallurgical changes and the finished surface is free of sharp edges. A hand held grinder shall not be used on the running surface or side of the rail.

(r) Marking and records, marking and records shall be in accordance with section 7.8.

(s) Qualification to AS 1085.20 statement that the procedure has been qualified to this standard.

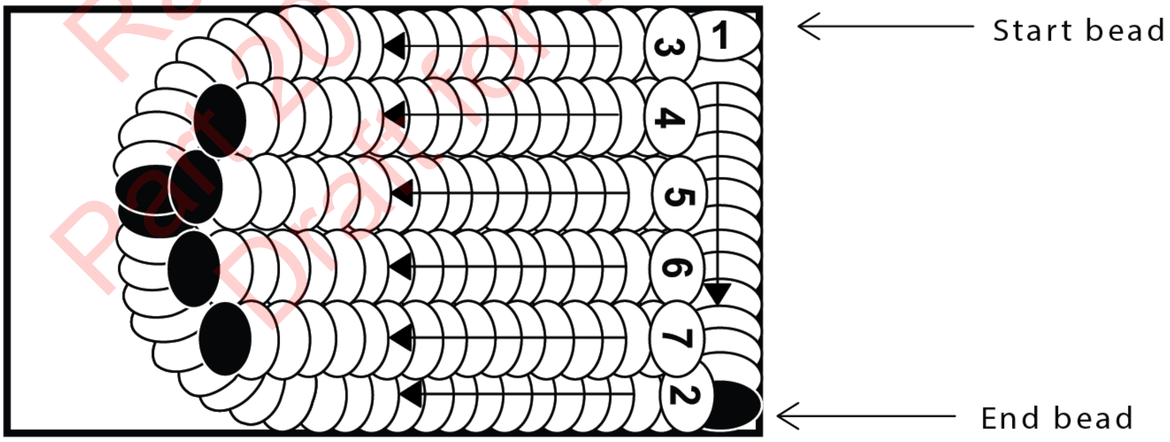


Figure7.2 Typical pattern of weld repair of rail end

7.6 Maintenance of equipment

The equipment shall be maintained in accordance with a written procedure.

7.7 Inspection and testing of finished weld

Inspection and testing of finished welds shall be carried out to ensure the weld satisfies the criteria given in Table 71 for surface finish, surface alignment (AT1, AT2 and AT3, as specified).

Finished welds shall be subjected to non-destructive testing in accordance with Appendix F.

Table 7.1 - Inspection of finished arc welds

Test	Test method (appendix)	Description	Pass criteria		
Visual inspection	E	Visual inspection of all surfaces	No regions of underfill, cracking, inclusions, lack of fusion, gas porosity, slag inclusions, grinding, burns, spatter or arc strikes		
Surface alignment tolerances	E	Alignment tolerance grade * (Note 1,2)	Vertical	Horizontal	Maximum slope angle on top of rail
		AT1	0.0 mm ±0.3 mm	±0.5 mm	±7 milliradians (Note 2)
		AT2	0.0 mm +0.5 mm	±0.5 mm	Limit to be specified by the purchaser
		AT3	Limit to be specified by the purchaser	Limit to be specified by the purchaser	Limit to be specified by the purchaser
Non-destructive test	F	Internal imperfections	Railway owners should determine the limits for internal imperfections. Suitable values are given in Appendix F. See note 5.		
		Magnetic particle inspection	2 mm maximum linear indication		

NOTES:

1. The grade is specified for the application. Selection of tolerance level will affect the loads experienced at the weld and thus the expected life of the joint for given track conditions and level of traffic.
2. Note that rail in-track can have a downward deflection due to long term service. In this case, alignment should match the overall rail curvature, and not introduce a local peak. An electronic straightedge should be used to measure and record the final alignment.
3. Measured over a distance of 100 mm along the rail surface and 50 mm either side of the weld centre-line. (definition 1.4.30).
4. An AT1 tolerance grade would be applicable for a high speed passenger line. An AT2 tolerance grade would be generally applicable for main lines.
5. MPI should only be carried out on the top and side of the head, after grinding.

7.8 Markings and records

7.8.1 Marking

Unique markings shall be incorporated onto the rail web of each weld. The marking shall be in letters of not less than 10 mm high and shall remain legible for a minimum period of 12 months from the date on which the weld was made.

7.8.2 Records

A record of the procedure (weld return) shall be kept, which shall include the weld number, date, location, welding information, identification of the welder, inspection and testing, consumable tradename and process type.

Appendix A Hazard register

To be inserted.

Appendix B Guidance on this standard

(Informative)

B.1 General

The aim of this standard is to ensure that rail welds perform as follows:

(a) The properties and durability of finished weld and the heat-affected zone match as close as possible those of the parent rail.

(b) Welds do not introduce weaknesses into the rail that reduce the properties of the rail below acceptable limits (that is, the finished weld and the heat-affected zone to have the required properties).

(c) Provide a continuous running surface on the rail.

(d) Welds do not introduce bulges, dips or angles into the running surface which will adversely affect the dynamic response of railway vehicles.

The standard is intended to be used by owners and maintainers of railway track to give confidence that welds carried out are of a specified quality. The provision of tests and pass criteria will assist in setting up new processes and in training staff.

Information presented in this standard may also be used in developing quality control procedures for production welding using the processes described.

B.2 Information on methods not covered by this standard

This Standard is not intended to preclude the use of any welding processes, new materials, or consumables, which do not comply with the specific requirements of this standard or are not mentioned in it.

Qualification should be on a similar basis and to an equivalent level of confidence as given for the methods covered in this Standard.

B.3 Aluminothermic welding – designation of weld types

The following designations should be used to identify particular aluminothermic weld types:

(a) SGW standard gap weld with an initial rail gap up to and including 40 mm. It may be supplied with or without reinforcement under rail foot.

(b) WGW wide gap weld with an initial rail gap greater than 40 mm.

(c) SJW standard junction weld used to weld dissimilar rail sections using an initial rail gap of up to and including 40 mm.

(d) LPH long preheat process requiring a preheat temperature of 900 °C to 1000 °C at the rail ends prior to welding.

(e) SPH short preheat process requiring a preheat temperature of 600 °C to 700 °C at the rail ends prior to welding.

(f) HRW head repair weld.

B.4 Aluminothermic welding - quality control of production of consumables

The production of consumables for aluminothermic welding may be monitored using tests appropriate for the purpose. The tests to be carried out, the sampling methods and frequency of testing and retesting should be specified, as appropriate for the situation and as agreed by the contracting parties (e.g. by setting acceptable quality levels).

NOTE: For guidance on demonstrating compliance, see appendix C.

The following tests are typically used:

(a) Visual inspection.

(b) Weld metal hardness test (see appendix G).

(c) Chemical analysis (see appendix J).

(d) Slow bend test (see appendix K).

Other tests, such as ultrasonic testing, may be used.

Where individual test welds fail to meet the specified requirements, retesting may be carried out on additional test welds manufactured using consumables from the same batch (see appendix N).

Appendix C Information to be supplied by purchaser

(Informative)

C.1 Flash butt welding

The following information should be supplied when ordering or specifying:

(a) The profile, material grade and manufacturer of the rails to be welded.

(b) Alignment tolerance grade.

(c) Any additional requirements for shearing or grinding of the finished weld.

(d) Any requirements for drilling of ends of welded strings.

(e) Any special requirements for marking or provision of records.

(f) Requirements for weld quality acceptance, if these vary from those provided in Appendix F.

NOTE: The web fatigue test may be specified as an optional test for qualification of flash butt welds.

C.2 Aluminothermic welding

The following information should be supplied when ordering or specifying:

(a) The profile, material grade and manufacturer of the rails to be welded.

(b) Alignment tolerance grade.

(c) Any additional requirements for shearing or grinding of the finished weld.

(d) Which of the three width levels of visible heat-affected zone is required (see table N3, appendix N).

(e) Which of the three width levels of heat-softened zone is required (see table N3, appendix N).

(f) Whether the staircase fatigue test (Appendix L, paragraph L.2.8 is required in preference to the past-the-post test (appendix L, paragraph L.2.7).

(g) Requirements for weld quality acceptance, if these vary from those provided in Appendix F.

(h) Whether the fatigue test for web of welded section (Appendix L, paragraph L3) is required.

C.3 Electric arc welding

The following information should be supplied when ordering or specifying:

(a) The profile, material grade and manufacturer of the rails to be welded.

(b) Type of welding to be used.

(c) Alignment tolerance grade.

(d) Requirements for weld quality acceptance, if these vary from those provided in Appendix F.

Appendix D Qualification of personnel

(Normative)

D.1 General

Welding shall be performed, supervised and inspected by qualified personnel with appropriate accreditation. Such qualification shall include appropriate experience in welding of steel rails.

Evidence of the qualification of welding personnel shall be available on site. Records shall include the particulars of any tests passed during qualification.

Qualifications should take into account:

(a) rail preparation;

(b) rail welding;

(c) finish grinding;

(d) inspection;

(e) non-destructive testing; and

(f) supervisors.

Welders shall have demonstrated competency in the application of the relevant welding procedure and materials.

Unless otherwise specified by the rail infrastructure manager, workers who are not qualified welders are only permitted to grind welds provided they hold current units of competence required by the Rail Industry Competency Matrix (Track and Civil) for the role 'Rail welder (aluminothermic), other than:

i. TLIW3015 – Weld rail using aluminothermic welding process; and

ii. TLW3035 – Heat and cut materials using OXY-LPG.

D.2 Welders

Welders shall be qualified to perform the welding procedures on which they will be employed. Qualification shall be based upon the following:

(a) For flash butt welding, welders shall be given training in the welding procedures and shall make the required test welds as specified in paragraph D3.

(b) For aluminothermic welding, welders shall be given training in the welding procedures and shall make the required test welds as specified in paragraph D3.

NOTE: Qualification may be specific to the welding process used for the manufacture of test welds.

(c) for metal arc welding, welders shall be given training in the welding procedures and shall make the required test welds as specified in paragraph D3.

A welder already qualified shall be required to re-qualify as follows:

i. For flash butt welding, every 2 years or where less than 500 welds are performed within a 12-month period.

ii. For aluminothermic welding, every 2 years or where less than 50 welds are performed within a 12-month period.

iii. For metal arc welding, every 2 years provided the welder has been working within the range of qualification and has been producing welds of an acceptable quality, or where no welds have been performed in the previous 6 month period.

AS 2980 provides guidance on the initial qualification, requalification and prolongation of welders for fusion welding.

D.3 Qualification testing of welders

A welder not already qualified or needing requalification shall demonstrate an ability to comply with the appropriate requirements of this Standard by performing a minimum of three test welds while observed by an assessor qualified by the manufacturer to confirm compliance with the welding procedure. This verification must be demonstrated for the actual aluminothermic welding process that is being used in-track. The welds shall be tested as follows:

(a) For flash butt welding: appendices E and F.

(b) For aluminothermic welding: appendices E and F.

(c) For metal arc welding: appendices E, F, and paragraphs G1 and G4, Appendix G.

Positioning of the test pieces relative to the welder shall simulate the rail position on the track.

D.4 Requalification testing of welders

Welders shall be requalified after a period of no more than two years from the date of the previous qualification.

Appendix E Visual inspection and alignment

(Normative)

E.1 Visual inspection

Following completion of the weld and final grinding, the entire weld shall be inspected including the ground weld surface, the heat-affected zone on either side of the weld and the as-cast weld surface (where applicable).

Evidence (including size and position) of the following shall be identified, recorded and reported:

(a) Cracks.

(b) Tears.

(c) Gouges.

(d) Gas porosity.

(e) Shrinkage porosity.

(f) Slag or sand inclusions.

(g) Underfill.

(h) Weld shape and contour.

(i) Fins.

(j) Electrode burns.

(k) Grinding burns.

(l) Hammer marks.

(m) Cold laps.

(n) Glazing due to excessive heating of mould surface.

E.2 Joint geometry test

E.2.1 Surface alignment

Weld straightness shall be measured in both vertical and horizontal directions over a distance of 500 mm on both sides of the weld centreline, using a metal straightedge or other device manufactured for the purpose.

Weld straightness shall be measured by a procedure that is not less accurate than that of placing across the weld a 1 m rectangular steel straightedge such that the centre of the straightedge is within +- 20 mm of the centre of the weld.

The straightedge shall be manufactured in accordance with paragraph E.2.3 and calibrated in accordance with paragraph E.2.4 (see figures E.1 to E.5).

The maximum deviation of the rail from the straightedge shall be measured in both vertical and horizontal directions in millimeters and the measurement recorded.

Alternatively, a modified straightedge, having lugs on each end as shown in figure D6, may be used as a set up tool

For aluminothermic welding, the lateral measurement shall be made on the gauge side of the rail.

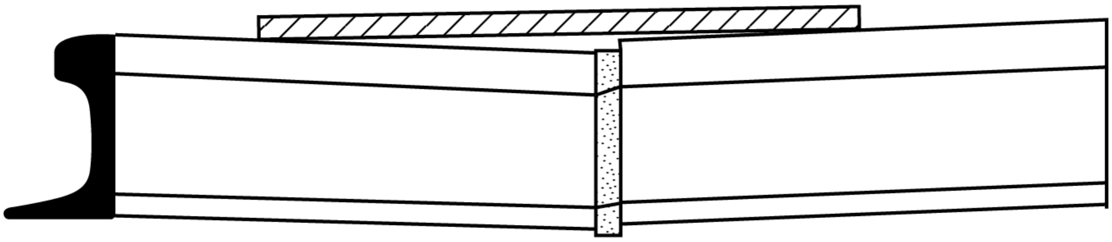


Figure E-1 Joint geometry – surface alignment method – vertical (dip)

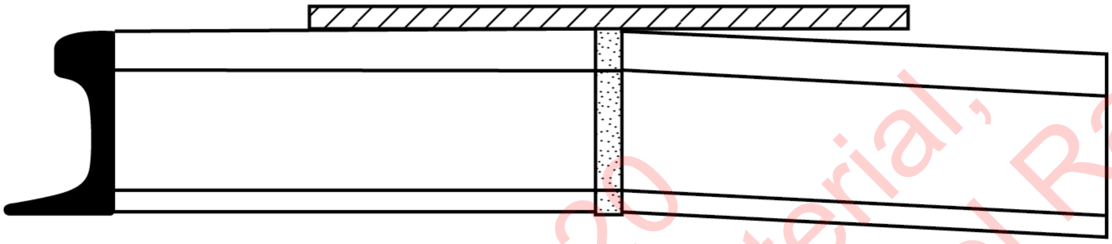


Figure E-2 Joint geometry – surface alignment method – vertical (peak)

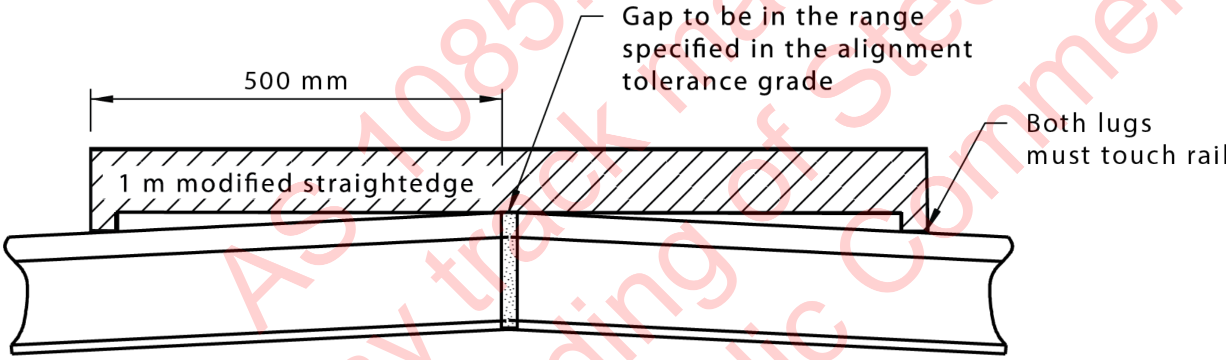
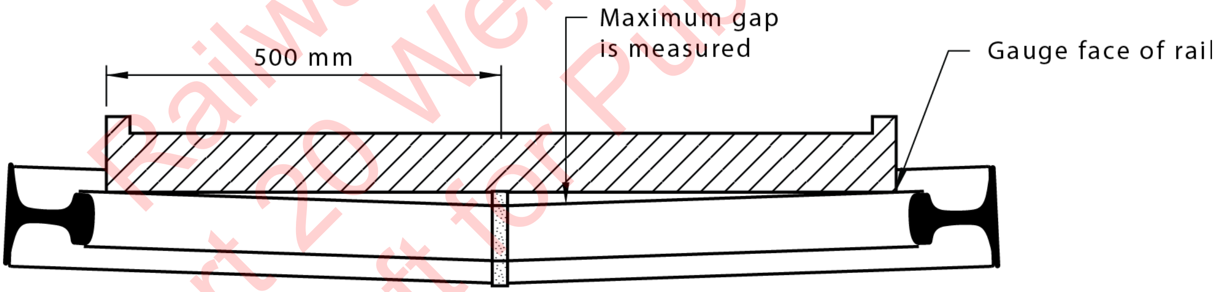


Figure E-3 Joint geometry – surface alignment method – vertical (peak) – alternative



NOTE: For curved track the surface alignment method differs. The curved track alignment method and tolerance should be prescribed in the relevant industry operating standards.

Figure E-4 Joint geometry – surface alignment method – lateral (for straight track)

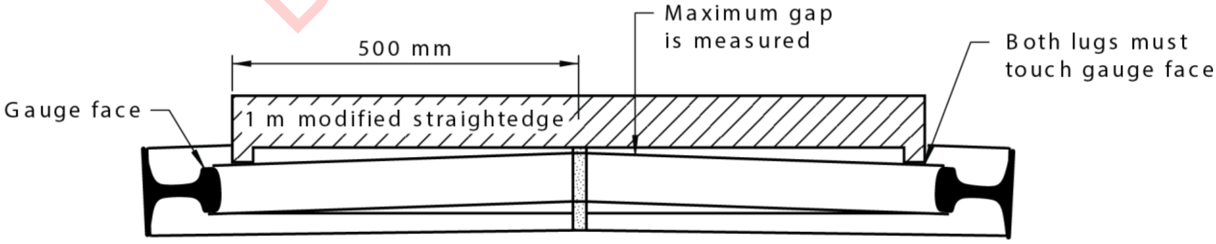
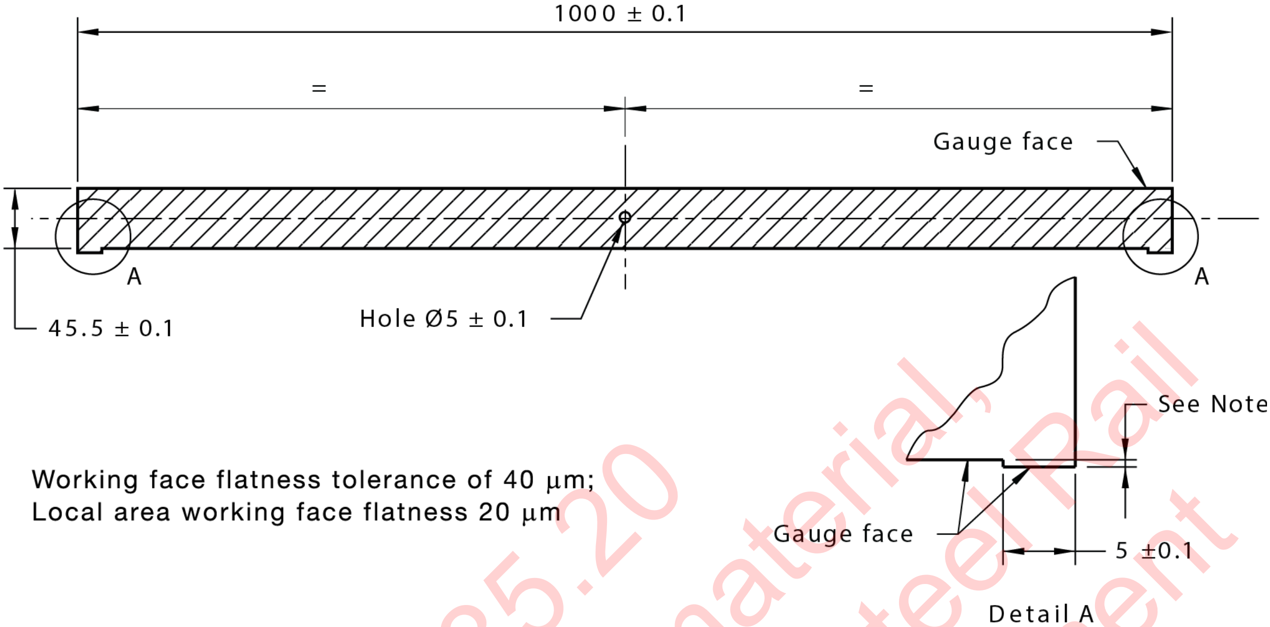


Figure E-5 Joint geometry – surface alignment method – lateral (for straight track)- alternative



DIMENSIONS IN MILLIMETRES

Figure E-6 – Modified straightedge

A separate modified straightedge shall be used for each surface alignment tolerance grade (see tables 2.1, 3.1 and 4.1). The size of the lug (detail A) is 0.3 mm, 0.5 mm, or as defined by the purchaser, and shall be stamped on the straightedge. Tolerances for the lug shall be ±0.05 mm.

E.2.2 Surface slope

After grinding is completed, the top and sides of the railhead shall be checked to ensure it is smooth with no steps. The surface slope of the top of the rail shall be determined for a distance of 500 mm either side of the weld. Individual measurements shall be taken over a distance not greater than 50 mm. The surface slope may be either measured using a device manufactured for the purpose or derived from measurements taken with an electronic straightedge. The maximum slope on both sides shall be recorded in milliradians.

NOTES:

1. This test is a requirement for welds made to alignment tolerance grade AT1 in tables 3.1, 4.1, 5.1, 6.1 and 7.1.
2. This test may be performed using commercially available instruments.
3. Instruments that use different gauge lengths can give different results.

E.2.3 Manufacture of straightedges

Straightedges are to be manufactured to reliably measure completed welds accurately. Three types of straightedges may be used, as follows:

(a) Master steel straightedge.

(b) Working steel straightedge.

(c) Electronic or optical straightedges.

The type of straightedge is not restricted to one design. Generally, the rectangular steel type straightedge is the most common. Australian Standard AS 1003 may be used as a guide for the manufacture of this type of straightedge. However, allowable tolerances in AS 1003 will be tighter that those required by this Standard.

Tolerances for steel rectangular straightedges shall be as follows:

i. Minimum thickness of 6 mm.

ii. Working face flatness tolerance of 40 µm.

iii. Local area working face flatness of 20 µm.

E.2.4 Calibration of straightedges

Straightedges shall be calibrated in accordance with a documented method which will depend on usage, any signs of damage, etc.

The recommended calibration intervals and limits are provided in Table E.1.

Table E.1 Recommended calibration intervals

Item	Calibration interval	Accuracy of calibration
Master steel straightedge	12 months initial 24 months thereafter	Refer to AS 1003—1971 Section 5, ACCURACY
Working steel straightedge Working steel straightedge nibs (modified steel straightedges only)	6 monthly	As required in paragraph E2.3(b)
Electronic or optical straightedges	As per manufacturer's recommendations or monthly.	As per manufacturer's recommendations or ±0.05 mm.

NOTE: Additional calibration will required if a straightedge is damaged or dropped, twisted etc.

E.3 Grind tolerances

E.3.1 Maximum permitted deviations

The maximum grinding deviations, with respect to the approved rail profile, shall be as shown in Figure D.7.

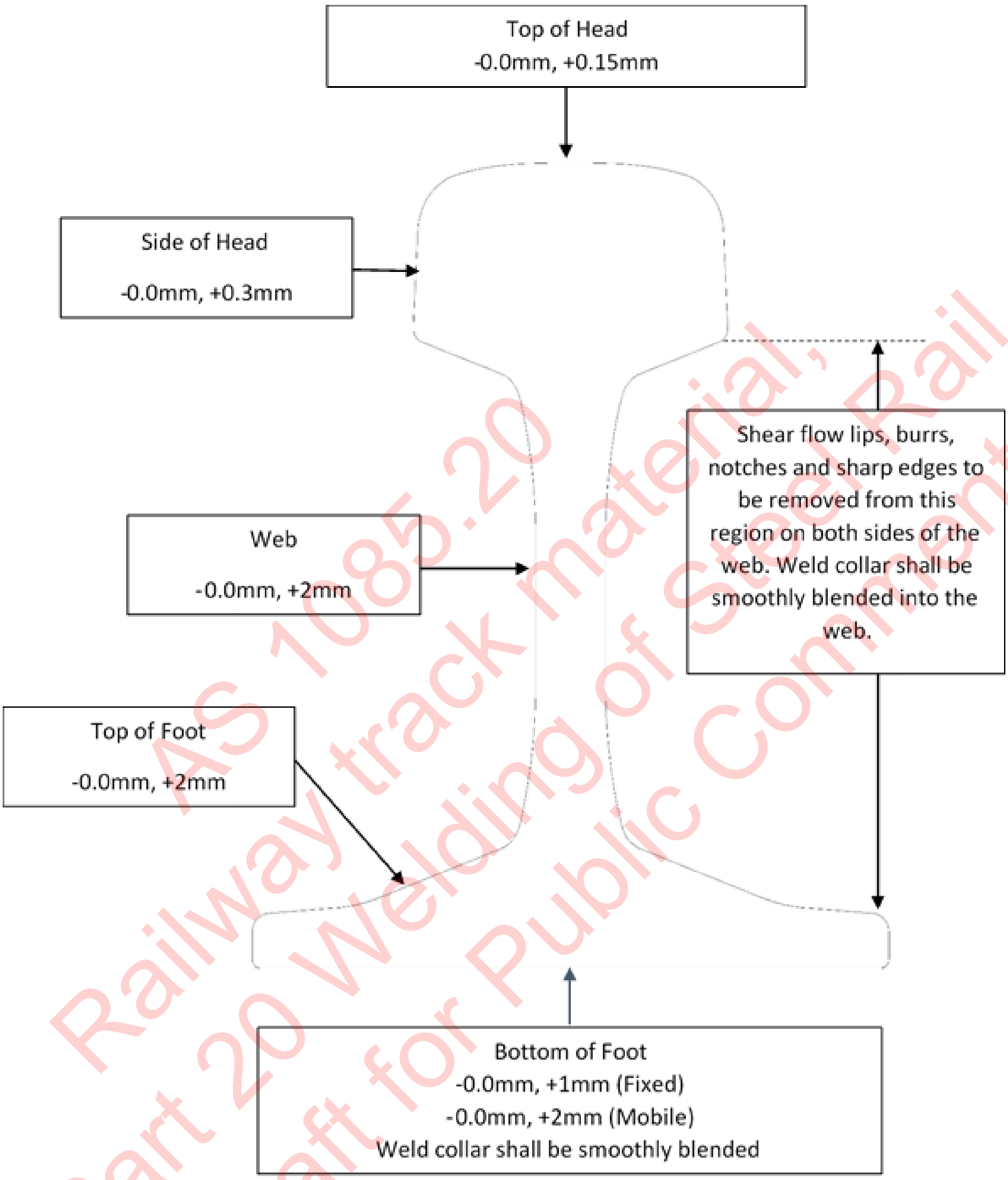


Figure D.7 – Weld finish grind tolerance

E.3.2 Weld collar test

The outstand of metal at the collar shall be tested using a gauge designed for the purpose of measuring the height of a fillet weld. The rail web, upper side of the rail foot and the underside of the rail foot shall be inspected.

NOTE: The weld collar test is for flash butt welding only.

E.4 Size of imperfections

The maximum dimension of any pores, slag inclusions, sand inclusions or cold shuts shall be measured as follows and the number for the head, web and foot recorded:

(a) Group in size bands:

i. 1... (>0 mm to 1 mm)

ii. 2... (>1 mm to 2 mm)

iii. 3... (>2 mm to 3 mm)

iv. A weld with any of the above defects that exceeds 3 mm in the longest dimension is unacceptable.

(b) Where multiple imperfections are revealed, they shall be counted and measured as a single imperfection if they are less than 1 mm apart. Areas containing micro-porosity or inter-dendritic shrinkage are not counted as single imperfections and therefore reported separately.

NOTE: For qualification, the number of welds to be examined is specified in appendix N as the sum of those in which imperfections are detected using ultrasonic testing, slow bend test and fatigue test.

Appendix F Non-destructive testing

(Normative)

F.1 Scope

This appendix specifies the requirements for non-destructive testing of welds for the qualification of flash butt, aluminothermic, aluminothermic head repair and arc head repair welding procedures.

The applicable non-destructive testing method for each welding procedure is given in Table F.1.

Table F.1 – Non-destructive tests

Inspection method	Applicable welding process			
	Flash butt	Aluminothermic	Aluminothermic head repair	Arc head repair
Visual inspection	✓	✓	✓	✓
Magnetic particle inspection	✓	✓*	✓*	✓*
Dye penetrant inspection	✓o	✓o*	✓o*	✓o*
Ultrasonic inspection	✓	✓	✓	✓
Phased array ultrasonic test (PAUT)	✓	✗	✗	✗

Legend
✓ applies to the process
✗ does not apply to the process
** top and sides of head only*
o Optional testing method

NOTE: The specified testing procedures are also applicable to the routine (field) testing of new welds.

For all new welds, the product standard, specification or application code (i.e. sentencing, accept/reject criteria) shall be specified by the purchaser.

Alternative non-destructive test methods, including other ultrasonic test methods, may be used provided they are capable of providing the discontinuity detection requirement described in this Appendix, and agreed between purchaser and supplier.

F.2 Testing of weld procedure qualifications and finished welds for in service application

The head, web and foot of the rail containing the weld shall be examined in accordance with paragraph F3. The position and nature of any recordable discontinuity detected by the approved test procedure shall be reported in accordance with paragraph F6.

F.3 Methods of test

All test methods nominated for the examination of rail welds shall be supported by a written procedure. Application of the written procedure shall demonstrate its ability to detect discontinuities that could exist within the parent metal, heat affected zone and weld metal regions that would be detrimental to the performance of the weld.

Each procedure shall address the following:

(a) equipment to be used—type, specification, calibration requirements.

(b) qualification of personnel.

(c) regions of the welds to be tested.

(d) reference to applicable standards for the test method employed.

(e) surface preparation required.

(f) details of the testing procedure.

(g) any limitations of the test procedure to detect specific discontinuities.

The test method and procedure shall be approved by the rail infrastructure manager, with the following exception:

If an alternative test method and procedure is not submitted and approved for use by the relevant rail infrastructure manager, the test procedure set out in Section F.5, based on pulse echo ultrasonic test method, may be used.

F.4 Procedure for magnetic particle testing of rail welds

F.4.1 Scope

Magnetic particle inspection is mandatory for qualification testing. It is optional for acceptance testing and may be specified by the Purchaser if required. This procedure details the minimum requirements for the testing of rail welds using magnetic particle methods for the general detection of surface breaking discontinuities that could exist in the weld zones (parent, HAZ, weld metal) of new flash butt and aluminothermic welds. The procedure may also be used for electric arc head repairs utilizing the described tests for the repaired area only.

The MPI testing procedure shall be performed in accordance with the requirements of AS ISO 17638.

F.4.2 Qualification of personnel

Personnel carrying out this test procedure shall be qualified to the requirements of AS 3998 Level 2—Welds, or similar qualifications acceptable to the rail infrastructure manager, with demonstrated competency in application of this procedure and rail welding discontinuity recognition.

F.4.3 Equipment and calibration

AC electromagnetic yokes shall be calibrated and used in accordance with the requirements of AS ISO 17638.

Permanent magnets may be used as an alternative, if approved by the rail infrastructure manager.

F.4.4 Field directions and testing area

The AC electromagnetic yoke shall be energised in a longitudinal orientation across multiple locations across the weld and heat affected zone to maximise the likelihood of identifying indications that are transverse to the rail. At a minimum, the sides of the web, including the under head region, the web, the top of the foot and the sides of the toes shall all be examined, with the yoke moved and energised to ensure that these locations are completely covered by this assessment. If there is access to the underside of the foot, this should be examined as well.

Examination of the welds shall be carried out:

(a) at least 50 mm on either side of the fusion line for flash butt welds, and

(b) a maximum of 110 mm from the weld centre line aluminothermic welds.

F.4.5 Acceptance levels

Linear indications that exceed 2.0 mm in length are unacceptable in any of the regions examined.

Linear indications that are longitudinal to the axis of the rail at the centre of the web in the bond line region of flash butt welds that exceed 2.0 mm in length are unacceptable.

Porosity (either single or cluster) that exceeds 3 mm in diameter (which can be detected with or without the use of magnetic particle inspection) is unacceptable in any of the regions examined.

F.5 Procedure for ultrasonic testing of rail welds

F.5.1 Scope

This procedure details the minimum requirements for the testing of rail welds using pulse/echo, A scan ultrasonic methods for the general detection of discontinuities that could exist in the weld zones (parent, HAZ, weld metal) of new flash butt and aluminothermic welds. The procedure may also be used for electric arc head repairs utilizing the described tests for the repaired area only.

This procedure is written in accordance with the requirements of AS 2207. The requirements of AS 2207 shall be followed unless specifically modified by this procedure.

Phased array ultrasonic testing may be used as an alternative process for flash butt welds.

Personnel carrying out this test procedure shall be certified in ultrasonic testing to the requirements of AS 3998 / ISO9712 Level 2 welds, with demonstrated competency in application of this procedure and rail welding discontinuity recognition.

F.5.2 Equipment and calibration

F.5.2.1 Pulse/echo - A Scan

The ultrasonic flaw detector equipment to be used and its calibration requirements shall be in accordance with the requirements of AS 2207.

The time base shall be calibrated using an AS 2038 number 1 block or equivalent. Probe index points and angles shall be checked regularly using techniques as described in AS 2083. Probe angles shall be within ±2º of the angle nominated in this procedure.

Since the velocity of ultrasonic waves is temperature dependent, beam angle determinations should be made at a temperature similar to that which pertains to the working environment.

Additional probe angles may be used to maximize the response from the area of the weld, or any discontinuity, under interrogation.

F.5.2.2 Phased array testing equipment and setup:

A phased array ultrasonic device shall be used that:

(a) is capable of driving a 16 element deep penetration probe at 2.25 MHz, and

(b) can generate a TCG for all eight reference holes indicated on the sensitivity calibration rail as shown in Figure F1.

A deep penetration phased array probe shall be used, with a 2 mm pitch, 32 mm active aperature and 20 mm elevation. A compatible 60° shear wave wedge shall be used, with an oil based couplant between the probe and the wedge.

The phased array unit shall be set up with a sectorial scan of 40° to 70°, angle step of 1°, with 16 elements. The scan settings shall be: One line-time, Scan area of 0 mm to 400 mm, scan resolution of 1 mm, scan speed of 8 mm/second. The pulser shall have an energy of 40 V, and a pulse repetition frequency of 8 Hz. The receiver shall use an averaging value of 4. The display should be set up to include a combination of the A Scan, Sectorial scan and C scan images.

Calibration shall be performed using the third hole down in the calibration rail shown in Figure F1 to perform the sensitivity calibration, with velocity to be calibrated using the radius of the AS 2083 No 1 Calibration block in accordance with the manufacturer's instructions.

Unless otherwise approved by a rail infrastructure manager, calibration rails of each size and grade of rail should be used. A single reference rail may be used for other rail with similar ultrasonic properties.

Time corrected gain shall be performed using all the side drilled holes in the reference rail in Figure F1, with 80 % screen height in each case. This shall be the reference sensitivity. The scanning sensitivity shall be the reference sensitivity plus 17 dB, which is also the evaluation sensitivity. Qualification of personnel

Personnel performing phased array ultrasonic testing shall in addition have completed appropriate training in the use of phased array equipment for the testing of flash butt welds in rails.

F.5.3 Surface preparation

The head of the rail and the top surface of the foot require surface preparation for scanning with ultrasonic probes. These regions shall be prepared for a distance of 250 mm from both toes of the weld.

The general requirements for surface preparation of AS 2207 shall be adhered to.

The running surface and sides of the head of the rail shall be prepared to SP4 (ground flush). The web and foot may be prepared to SP1 (undressed).

It is accepted that the surface finish achieved through rail grinding will not meet the 3.2 µm Ra required by AS 2207 and additional fine grinding is not practical. Rail ground surface is acceptable under this procedure providing the technician takes precautions such as thickening the couplant with a methyl cellulose powder to minimize surface attenuation, if the rail temperature is less than 30 °C. Similarly, for welds joining old rail corroded foot conditions can be experienced. Again, the technician must take precautions to minimize surface attenuation. As a minimum all scanning surfaces in the foot will be scraped to remove spatter and other contaminants and then wire brushed to remove surface rust. Any surface condition that adversely affects the integrity of the test shall be identified in the report.

F.5.4 Couplant

Couplants shall possess good wetting characteristics and be compatible with the steel under test. In general water is used as the couplant for testing rail welds. This can be thickened with a methyl cellulose powder, though this should be avoided if the rail temperature is above 30 °C. Detergents shall be added to improve couplant on greasy surfaces.

The same couplant to be used during the test should be used when establishing sensitivity. Alternatively, a couplant with similar sound energy transfer characteristics may be used on the reference blocks.

F.5.5 Sensitivity

F.5.5.1 Head and web – conventional ultrasonics

The parent metal shall be scanned to ensure that no discontinuities exist that could interfere with the integrity of the test. The evaluation sensitivity shall be the gain required to bring the signal from a 3.0 mm diameter side-drilled hole (SDH) at the same beam path length as the discontinuity, to 80 % screen height. Time Corrective Gain (TCG) is to be used for the reference level sensitivity. TCG setups shall be created using the Sensitivity Calibration Rail.

The gain shall be increased by an additional 6 dB for scanning.

All indications which at evaluation sensitivity are greater than 40 % screen height shall be recorded, sized for height and classified according to the client's defect classification documentation.

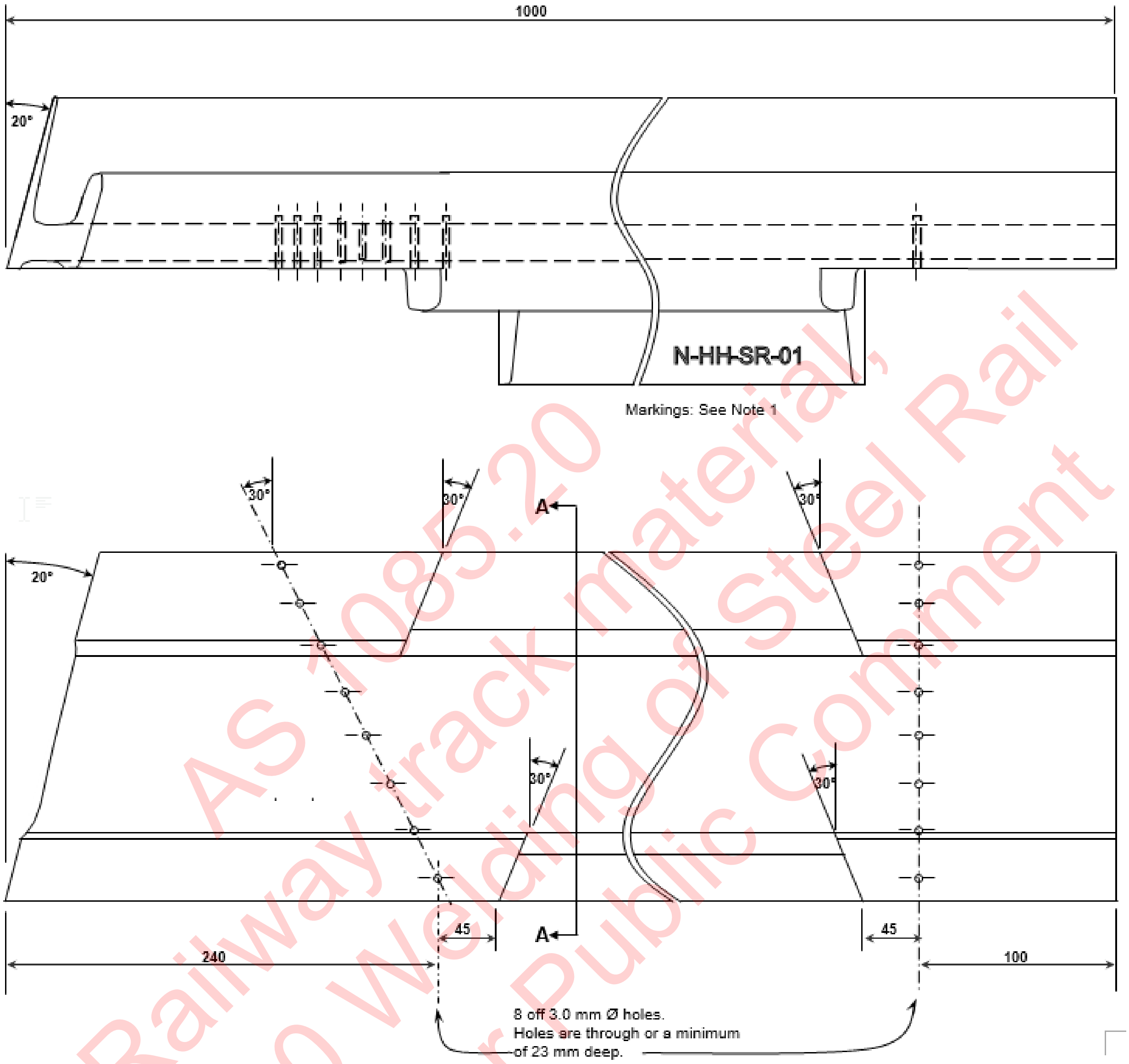


Figure F.1: Sensitivity calibration rail

F.5.5.2 Rail foot

The inspection of the rail foot requires the use of the sensitivity calibration rail foot shown in Figure F2 below. The scanning sensitivity shall be set in accordance with AS 2207. This requires the reflection received from a 3.0 mm side drilled hole 30 mm deep to be set at 80 % FSH with an additional 6 dB of gain.

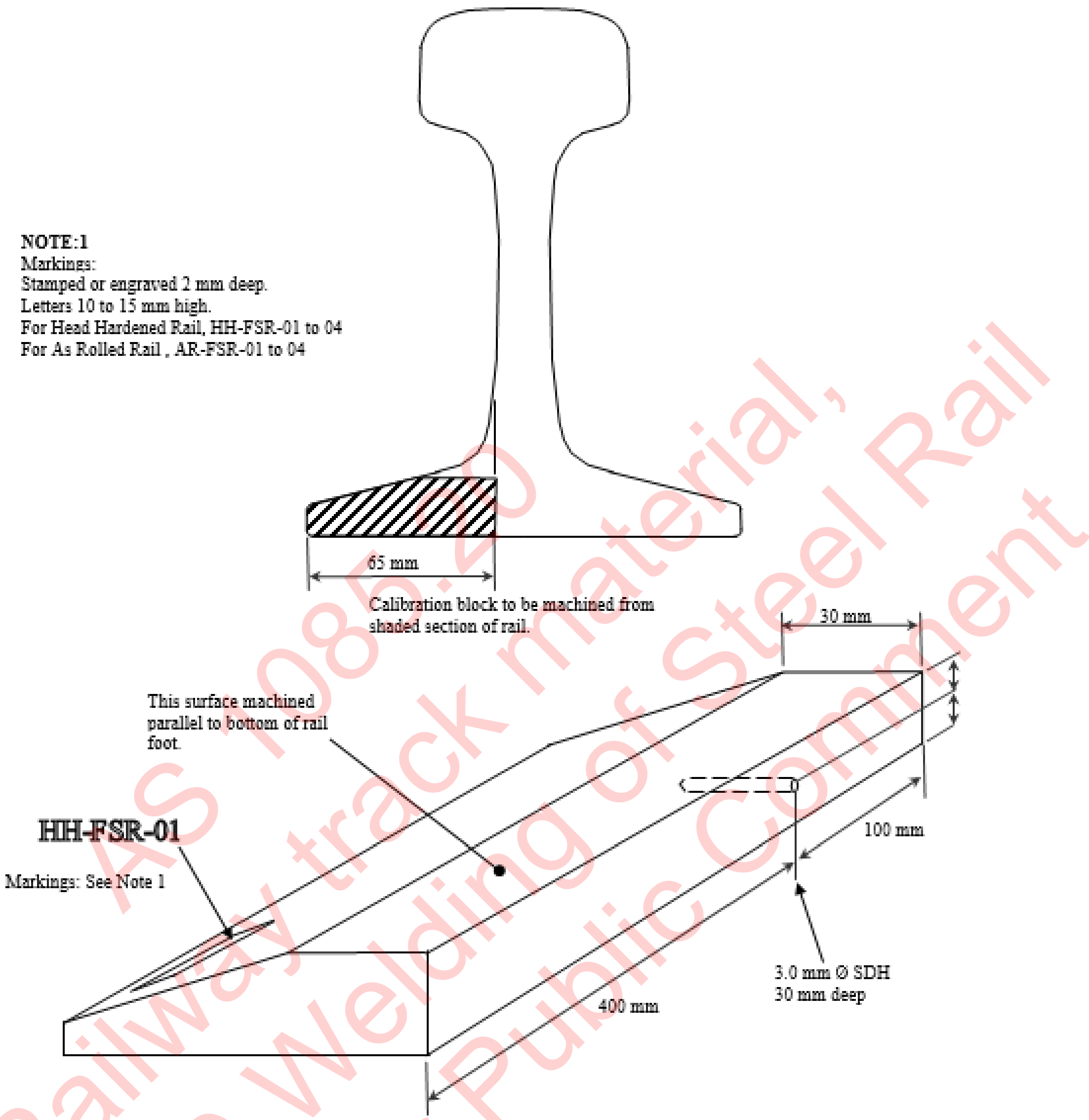


Figure F.2: Sensitivity calibration rail foot

Evaluation sensitivity shall be in accordance with AS 2207 Level 2. This is the gain required to bring the signal from a 3 mm side drilled hole with a depth 30 mm, at the same beam path length as the discontinuity to 80 % FSH. At this gain setting all discontinuities producing echoes equal to or greater than 40 % FSH shall be evaluated.

Time Corrective Gain (TCG) is to be used for the reference level sensitivity. TCG setups shall be created using the Sensitivity Calibration Rail Foot.

F.5.6 Probe selection and methods of scanning – standard ultrasonics

F.5.6.1 General

The examination of the weld shall be carried out on scan lines parallel to, or at right angles to, the weld axis and at a separation not exceeding the width of the transmitting probe crystal. While scanning probe swivel of ±10° is encouraged for the detection of unfavourably orientated discontinuities. When testing the foot swivel should be slow and deliberate to compensate for the non-parallel geometry of the foot flange.

Instances where it is not possible to scan from the specified scanning surfaces due to limitations of access shall be described in the report.

F.5.6.2 Probe types

Probes that shall be used during ultrasonic testing are described in table F.2.

Table F.2 - Probe types

Probe ID	Size	Type	Frequency	Angle	Focal depth
Normal	7 x 18 mm	twin crystal	2 MHz	0 degrees	Not focussed
Option normal	10 mm diameter	single crystal	4 MHz	0 degrees	N/A
38 – 45 degree	14 x 14 mm	single crystal	2 - 2.5 MHz	38 – 45 degrees	N/A
70	14 x 14 mm	single crystal	2 - 2.5 MHz	70 degrees	N/A

F.5.6.3 Scanning Positions

Scanning positions are designated as follows: Probe ID/XX-Y-Y/#

Where:

(a) Probe ID = Probe description (See Table F.2).

(b) XX = Location abbreviation. (See Table F.3)

(c) -Y = Sub-location abbreviation. (See Table F.3)

(d) # = Squint angle. Positive values are towards the centre of the rail. Negative values are towards the edge of the rail.

Examples:

i. 38-45/HR-C/0 -Use a 14 x 14 mm 45º 2 MHz probe and scan from the centre of the running surface of the head.

ii. 70/F-G-T/25-Use a 14 x 14 mm, 70º 2 MHz probe and scan from the toe of the foot on the gauge side with the probe angled at 25 degrees towards the web.

Table F.3 - Probe locations

Location	Abbreviation	Sub-location	Abbreviation		
Running surface of the rail head.	HR	Gauge side	-G	Pitch and Catch	P&C
		Centre	-C		
		Field side	-F		
Gauge side of the rail head.	HG				
Field side of the rail head.	HF				
Rail web.	W	Gauge side	-G		
		Field side	-F		
Top surface of the rail foot.	F	Gauge side	-G	Toe	-T
		Field side	-F		

Location	Abbreviation	Sub-location	Abbreviation		
Side of the rail foot.	FS	Gauge side	-G		
		Field side	-F		

F.5.6.4 Scans Required

F.5.6.4.1 Pulse / Echo – A Scan

The rail and rail welds shall be scanned as described in Table F.4. A total test of a weld or a section of rail is achieved by performing all 18 scans.

As a minimum scan number 1, 2, 6, 12 and 14, described in Table F.4 shall be undertaken for new aluminothermic welds in track: Partial or specific test of a weld or a section of rail may be specified by using the scan numbers in the left hand column of the table.

Scanning requirements and discontinuity and defect description may be aided by using the scan numbers to describe the probe location from which the discontinuity or defect was detected.

Table F.4 Scan Descriptions

No.	Scan	Range (mm)	Scan details	Volume scanned	Purpose of Scan
1	Normal/HR	Min 400	400 mm either side of weld	All of head, and web	Check for discontinuities that will obstruct angle probe and pitch catch scans
2	Normal/HR	Min 400	Weld and Heat Affected Zone weld collar and 25 mm either side.	All of head and web, weld and HAZ	Check for reflective discontinuities in weld. Check for non reflective discontinuities (shrinkage) that cause loss of BWE
3	Normal/HG Normal/HF	Min 200	Weld and Heat Affected Zone weld collar and 25 mm either side.	All of head, weld and HAZ	Check for reflective discontinuities in weld. Check for non reflective discontinuities (shrinkage) that cause loss of BWE
4	SEB2-0/FF SEB2-0/FG	Min 200	Weld and Heat Affected Zone and 200 mm either side.	All of foot	Check for discontinuities that will obstruct angle probe and pitch catch scans
5	SEB2-0/FF SEB2-0/FG	Min 200	Weld and Heat Affected Zone weld collar and 25 mm either side.	All of foot, weld and HAZ	Check for reflective discontinuities in weld. Check for non reflective discontinuities (shrinkage) that cause loss of BWE
6	38-45-2/HR-C/0	400	From both sides of weld towards weld. Probe movement, start at 1.5 x rail height back from weld and scan in and through weld. Scan from centre only.	Scans the web and the central section of the foot and head.	Checks for lack of fusion, porosity and inclusions in the web, head and foot.

No.	Scan	Range (mm)	Scan details	Volume scanned	Purpose of Scan
7	SWB45-2/HR/GCF/0	150 min	From both sides of weld towards weld. Probe movement, start at 1.5 x head height back from weld and scan in and through weld. Cover full width of the running surface.	Scans the head.	Checks for lack of fusion, porosity and inclusions in the head.
8	SWB45-2/HR-G/+20 SWB45-2/HR-F/+20	150 min	From both sides of weld towards weld. Probe movement, start at 2 x head height back from weld and scan in and through weld. Cover full width of running surface.	Scans the under head radius.	Checks for lack of fusion, porosity, inclusions, at under head radius.
9	SWB45-2/HF/HG-0	300 min	From both sides of weld towards weld. Probe movement, start at 2 x head width back from weld and scan in and through weld. Cover full volume of rail head by skewing the probe up and down.	Scans the head.	Checks for porosity and inclusions in the head and planar defects at other than transverse orientation.
10	SWB45-2/FG/-25 SWB45-2/FF/-25	150	From both sides of weld towards weld. Probe movement, start 100 mm back from weld and scan in to edge of collar. Cover full width of foot.	Scans full thickness of foot at HAZ and edge of collar.	Checks for lack of fusion, in the top of the foot of the weld.
11	SWB45-2/FG/45 SWB45-2/FF/45	200	From both sides of weld towards weld. Maintain probe 10 mm from outer edge angled in. Probe movement, start 200 mm back from weld and scan in to edge of collar.	Scans opposite foot web radius.	Checks for lack of fusion, in the top of the foot of the weld.
12	SWB70-2/HR/GCF/0	250	From both sides of weld towards weld. Probe movement, start at 4 x head height back from weld and scan in and through weld. Cover full width of running surface.	Full height of rail head for full length of weld and HAZ	Check for lack of fusion at rail ends and inclusions, porosity and cracks within weld.
13	70-2/HF /HG-0	250	From both sides of weld towards weld. Probe movement, start at 4 x head width back from weld and scan in and through weld. Cover full volume of rail head by skewing the probe up and down.	Scans the head	Checks for porosity and inclusions in the head and planar defects at other than transverse orientation.
14	SWB70-2/HR-G/20	250	From both sides of weld towards weld. Probe movement, start at 4 x head height back from weld	Under head radius at edge of collar.	Checks for lack of fusion, porosity and inclusions at under head radius.

No.	Scan	Range (mm)	Scan details	Volume scanned	Purpose of Scan
	SWB70-2/HR-F/20		and scan in and through weld.	4 locations.	
15	SWB70-2/FG/0 SWB70-2/FF/0	200	From both sides of weld towards weld. Probe movement, start 200 mm back from weld and scan in to edge of collar. Cover full width of foot.	Scans full thickness of foot at weld and HAZ.	Checks for lack of fusion, porosity, inclusions, in the foot of the weld.
16	SWB70-2/FG/-10 SWB70-2/FF/-10	200	From both sides of weld towards weld. Probe movement, start 200 mm back from weld and scan in to edge of collar. Cover full width of foot.	Scans full thickness of foot at weld and HAZ.	Checks for lack of fusion in the bottom of the foot of the weld.
17	SWB70-2/FG-T/25 SWB70-2/FF-T/25	200	From both sides of weld towards weld. Maintain probe at outer edge angled in. Probe movement, start 200 mm back from weld and scan in to edge of collar.	Scans opposite foot web radius.	Checks for lack of fusion on the opposite foot web radius. Checks for inclusions and porosity in the centre of the foot.

NOTES:

1. MB4F May be used in lieu of SEB2-0 if required.
2. Care should be taken to resolve the difference between reflectors originating from surface features apparent in both flash butt welds, after shearing, and aluminothermic welds from reflectors originating from discontinuities.

F.5.6.4.2 Scanning pattern and records – phased array ultrasonics:

Each flash butt weld shall be scanned from both directions. Scanning shall be first towards the Up direction, and then towards the Down direction. In each case the scanning shall be from a location from which the foot of the weld is apparent in the sectorial scan through to the top of the weld and back again.

Scanning shall be at a consistent pace so as to produce a C scan image where the data fills the C scan and the data representing the Up direction scan is of a similar size to the data representing the Down direction scan.

At least one complete scan for each weld that is tested shall be recorded and saved using a data file naming convention as specified by the railway operator.

All scans shall be reported using the software of the equipment. The heat affected zone width shall be measured using the lateral cursors and rail height shall be measured using the depth cursors from the scans and included in the report. All indications at the fusion line at the evaluation sensitivity that have a screen height of greater than 40% shall be reported as a separate entry in the indication table of the report, and include the maximum amplitude of the indication, the depth of the top of the indication from the running surface of the rail, and the overall height of the indication from the top to the bottom.

F.5.6.5 Discontinuity sizing and evaluation

The size and position of all imperfections exceeding evaluation sensitivities stated above shall be determined, including lack of fusion, cracks, cold shut, porosity, inclusions and shrinkage. All such imperfections shall be recorded and reported using the notation illustrated in figure F3 and defined as follows:

(a) Height, the maximum vertical height of a defect.

(b) Width, the maximum horizontal length of a transverse defect.

(c) Length, the maximum horizontal length of a longitudinal defect.

Discontinuities shall be sized for height, width and length utilizing sizing techniques as described in AS 2207 (the 6 dB drop or the 'last significant echo'). When using angle probes to measure height care is required to ensure the height of the discontinuity is differentiated from probe movement.

The scanning positions from which the discontinuity is detected shall be included as this assists in describing the discontinuity.

All discontinuities shall be evaluated for compliance against the applicable product standard, specification or application code.

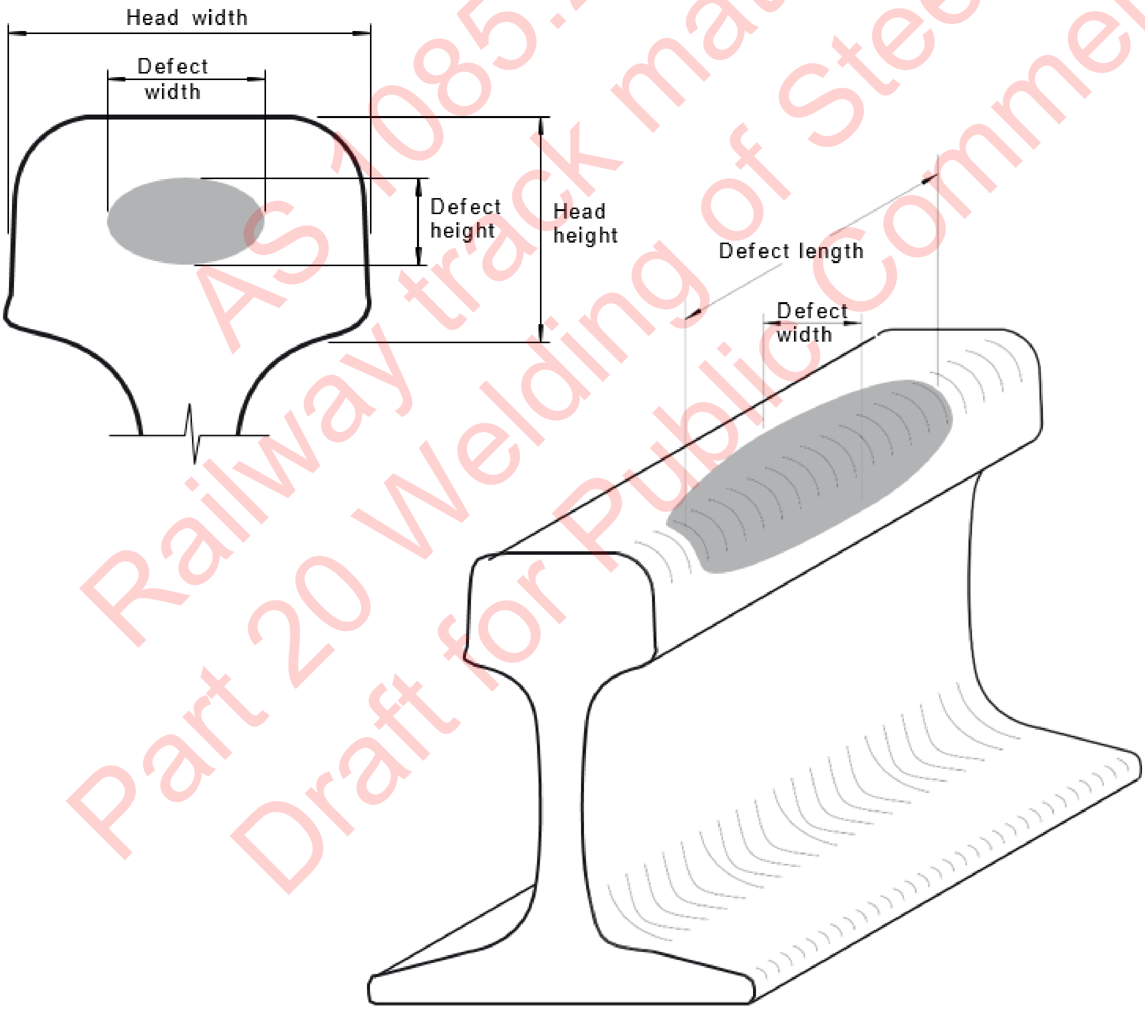


Figure: F.3 Discontinuity dimensions definitions

F.6 Record of test and reporting

The record of test shall be delivered in a report that will include at least the following information:

(a) The name of the laboratory or testing authority.

(b) Identification details of the welds tested.

(c) The relevant product specification or application code.

(d) The number of this Standard and or any other referenced standard or procedure used to establish the test method.

(e) The specific techniques used in the test method and any deviations from the approved procedure including limitations to access that would affect the test results.

(f) All test parameters required to uniquely specify the test to produce repeatability.

(g) The area tested and method of sizing.

(h) The serial number and unique identification of all equipment used.

(i) Details of any repairs carried out.

(j) Details of any retests.

(k) The test results and whether they comply with the product standard or application code.

(l) Any other information the purchaser requires for the assessment of the test results.

(m) The date and place of the test.

(n) Identification of the testing personnel.

(o) Phased array results shall be included as identified in section F.5.3.7.2

F.7 Product standard

Discontinuities detected by the relevant test method approved procedure shall be evaluated using a product standard, specification or application code nominated by the rail infrastructure manager.

For weld discontinuities detected by the ultrasonic test procedure described in section F4, the following acceptance criteria for qualification testing shall apply:

(a) Flash butt welds, table F.5 or F.6 for phased array UT.

(b) Aluminothermic welds, table F.7.

(c) Aluminothermic and arc rail head repair welds, table F.8.

Table F.5: Flash butt welds

Position	Vertically oriented	Horizontally oriented	Both vertical and horizontal	Foot defects
Head	≥ 5 mm (height)	≥ 5 mm (width)	-	-
Web	-	≥ 5 mm (width)	≥ 5 mm (height or width)	-

Position	Vertically oriented	Horizontally oriented	Both vertical and horizontal	Foot defects
Foot		0 mm (width)		0 mm (height or width)

Table F.6: Flash butt welds using phased array ultrasonics at evaluation sensitivity

Position	Vertically oriented	Horizontally oriented
Head	≥ 5 mm, 80% maximum amplitude	≥ 5 mm (width)
Web	≥ 20 mm, 80% maximum amplitude	≥ 5 mm (width)
Foot	≥ 10 mm, 80% maximum amplitude	
NOTE: Variation in HAZ width should be monitored.		

Table F.7: Aluminothermic welds

Position	Vertically oriented	Horizontally oriented	Both vertical and horizontal	Foot defects
Head	≥ 5 mm (height)	≥ 15 mm (width or length)	-	-
Web	-	≥ 5 mm (width)	≥5 mm (height or width)	-
Foot	-	0 mm (width or length)		0 mm (height or width)

Table F.8: Rail head repair welds

Position	Vertically oriented	Horizontally oriented	Both vertical and horizontal	Foot defects
Head	<5mm (height)	<1 mm (width or length)	-	-

Appendix G Hardness tests

(Normative)

G.1 Scope

This Appendix sets out the methods for hardness testing of welds.

G.2 Weld metal hardness for aluminothermic welding

G.2.1 General

Brinell hardness tests shall be carried out in accordance with AS 1816.1, using a 10 mm diameter tungsten carbide ball at 3000 kg load.

Impressions shall be made on a flat surface that is tangential to the rail crown at the point of intersection with the rail vertical axis in accordance with Figure G.1 with a spacing (Y) of 15 mm.

Three hardness values shall be determined for each weld.

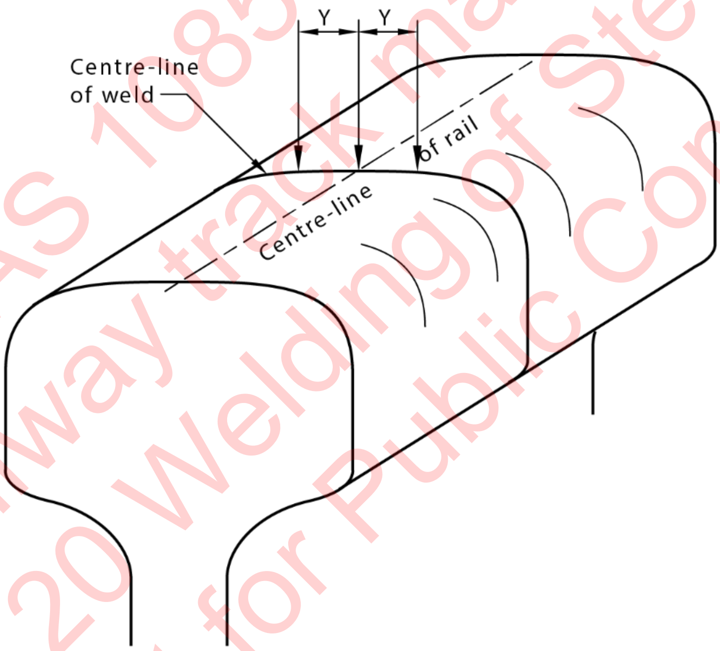


Figure G.1 Location of external hardness tests

G.2.2 Report

The following shall be reported:

(a) Date of testing and name of testing facility;

(b) Identification of the samples;

(c) All test values and the average Brinell hardness (BH);

(d) Reference to this test method (i.e., AS 1085.20, section G2, appendix G).

G.3 Hardness traverse for flash butt and aluminothermic welds

G.3.1 Principle

The purpose of the test is to provide an indication of the width of the softened zone, the maximum and minimum hardness in the heat-affected zone, and any off-centre softening.

Vickers hardness tests shall be carried out in accordance with AS 1817.1 with a minimum hardness of 10kg, except as follows:

The length of the traverse, and the spacing between individual indentations, shall be such that the resulting graph of hardness versus the distance from the weld centre line accurately describes the following parameters:

(a) The maximum and minimum hardness of the fusion zone.

(b) The width and minimum hardness of the softened zones.

(c) A minimum of ten (10) indentations into the parent rail on either side of the weld.

G.3.2 Procedure

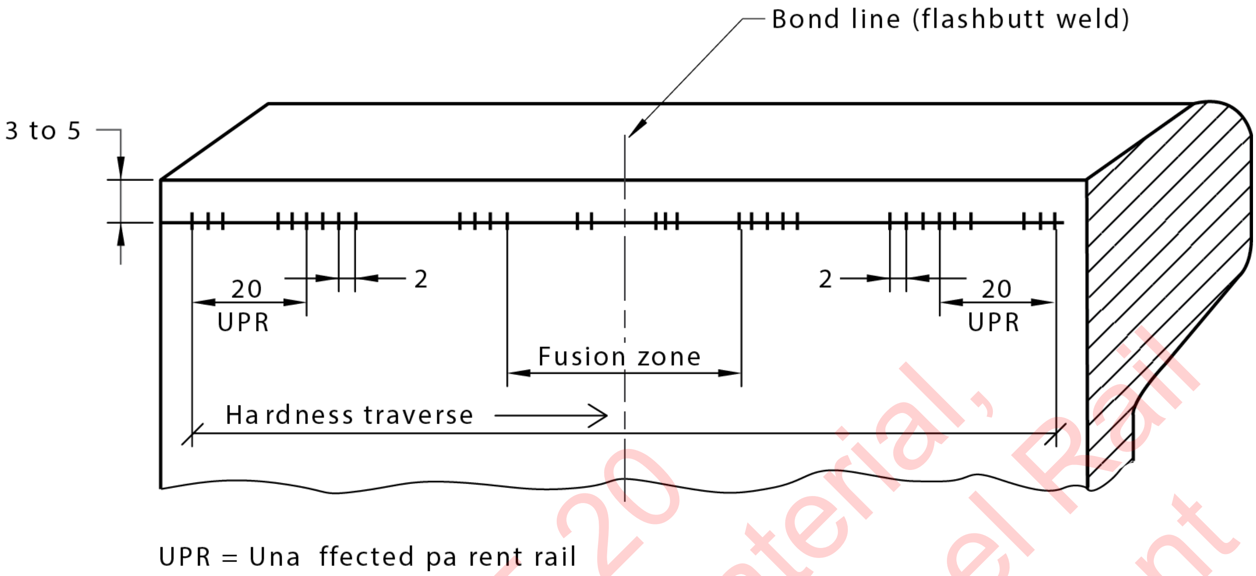
The procedure shall be as follows:

(a) Section the weld longitudinally along the centre-line of the welded rail so as to include the entire heat-affected zone on both sides of the weld and at least 20 mm of unaffected parent rail (see figure G2);

NOTE: Light etching should be carried out to define the weld zone and to allow hardness indentations to be properly positioned. Information about suitable etchants is given in AS 2205.5.1.

(b) Perform a hardness traverse using the Vickers hardness test method in accordance with AS 2205.6.1. The hardness traverse shall be on a line between 3 mm and 5, ±0.2 mm below the rail running surface on the longitudinal axis of the rail. Spacing between individual hardness indents shall be 2mm.
A reference position corresponding to the bond line in flash butt welds, and the centre of the fusion zone in aluminothermic welds, shall be used;

(c) continue each traverse across the entire weld region including the parent rails, heat- affected zones and fusion zone, and extending into parent rail on both sides of the heat-affected zone by 20 mm. Take a minimum of 10 hardness measurements in the unaffected parent rail on both sides of the weld.



NOTE: For flash butt welds, the fusion zone appears as a single line.

Figure G.2 Longitudinal hardness test location (Dimensions in millimetres)

(d) record the hardness measurements on a graph (see the typical graphs shown in figures G.3 and G.4).

(e) calculate the mean hardness of the parent rail and draw a line equal to the mean hardness on the hardness graph as shown (Line 1 in figure G.3).

(f) mark the measurement hardness line (Line 2 in figure G3) at a distance of X hardness points below the mean hardness line.

(g) the value of X varies with the rail grade as follows:

i. X = 10 HV for as-rolled rail.

ii. X = 25 HV for head-hardened rail.

iii. X = 25 HV at welds between two different rail grades

(h) Determine the heat-softened zone width as the distance between points A and B (as shown in figure G.3 and G.4).

(i) Point A is the first point of crossing below Line 2 when traversing from the parent rail and could be between hardness indents. Take note of section G3.3.

(j) Point B is the first point of crossing back above Line two after point A.

(k) Determine the average re-austenitised zone hardness for flash butt welded rails. This is defined as the area immediately adjacent either side of the bond line before the dip in hardness. In some cases this can coincide with all the hardness points between the bond line and point B.

NOTES:

1. For welds in which the hardness of the fusion zone falls below that of the parent rail, the width of the heat-softened zone can correspond to the entire width of the heat-affected zone.

2. For flash butt welds, it corresponds to the hardness of the austenitised zone.

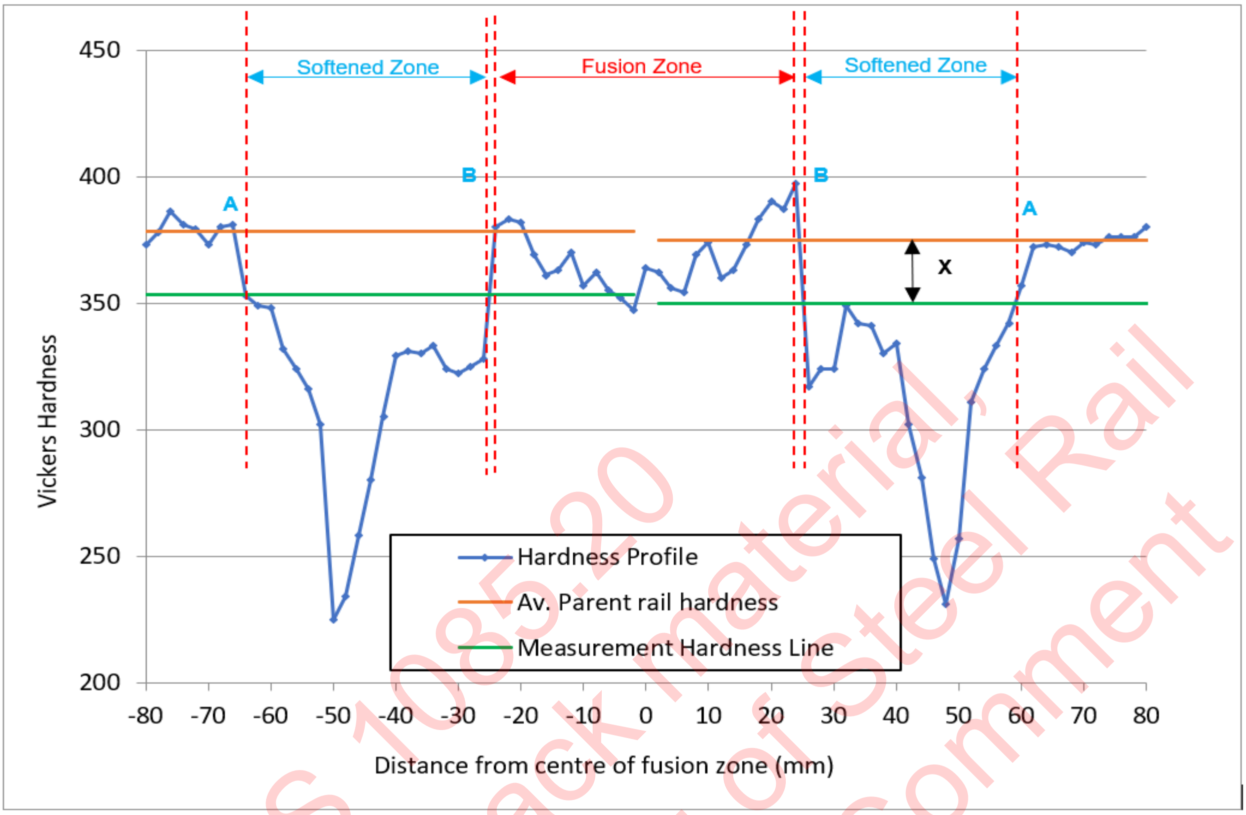


Figure G.3 Typical aluminothermic hardness profile

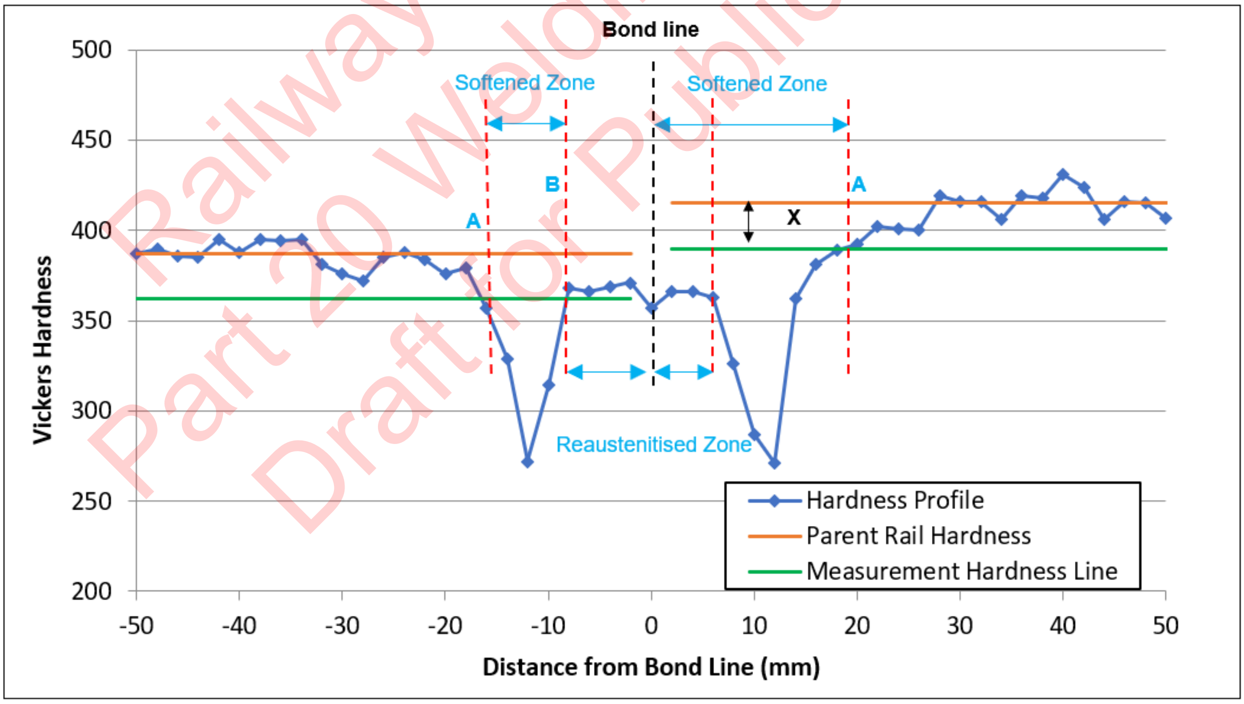


Figure G.4 Typical flash butt weld hardness profile across two different rail grades

G.3.3 Parent rail hardness variation

In some cases, the unaffected parent rail can have a large standard deviation of hardness about the mean, which will cause individual points within the unaffected rail to be below the measurement hardness line (line 2). For the purposes of heat-softened zone width measurement, individual points lying below the measurement hardness line may be ignored where the following apply:

No more than one hardness point of those used to define the parent rail mean hardness lies below line 2.

The hardness point lying below line 2 is more than 4 mm from point A of figure G3.

The parent rail hardness shall be calculated from hardness values that are no further than 50 mm beyond point A on either side of the weld. In the case of welds between two different rail grades, the parent rail hardness values shall be reported for both rails.

G.3.4 Report

The following shall be reported:

(a) Date of testing and name of testing facility;

(b) Identification of the samples;

(c) Hardness results and graph;

(d) The width of the heat-softened zone;

(e) Parent rail hardness;

(f) Average re-austenitised zone hardness

(g) Reference to this test method, i.e. AS 1085.20, section G3, appendix G.

G.4 Hardness traverse for arc welds

G.4.1 Principle

Vickers hardness tests shall be carried out in accordance with AS 1817.1, except that the spacing of the indentations shall comply with AS 2205.6.1

Impressions shall be made on a section across the rail and weld in three vertical traverses down from the top of the weld. The maximum hardness value is determined for each weld.

G.4.2 Procedure

The procedure shall be as follows:

(a) Section the weld transversely across the rail and weld (see figure G.5).

NOTE: Light etching should be carried out to define the weld zone and to allow hardness indentations to be properly positioned. Information about suitable etchants is given in AS 2205.5.1.

(b) Establish the unaffected parent rail hardness by testing well down the head below the weld and heat affected zones.

(c) Perform the hardness traverses using the Vickers hardness test method, in accordance with AS 2205.6.1. The minimum surface finish is 500 grit for 10 kg load, 240 grit for 20 kg.

(d) Continue each traverse vertically down from the top of the weld until three consecutive measurements indicate the traverse has reached the unaffected parent rail (see figure G4). This comparison shall be made to similar traverses in unaffected parent rail, as heat treated grades will have a variation in hardness with depth.

(e) Perform three traverses at the following positions (see figure G5):

  i. Down from the centre of the top surface of the rail.

  ii. On each side of the railhead, down from points 10 mm in from the outside edges of the railhead.

(f) Record the hardness values at each measurement.

(g) Determine the extent of the heat-affected zone and the weld metal, as shown in figure G6.

NOTE: Where doubt occurs as to the start of the unaffected parent metal, a similar approach may be used as given in section G3.2(b).

G.4.3 Report

The following shall be reported:

(a) Date of testing and name of testing facility;

(b) identification of the sample;

(c) hardness results, graph and maximum hardness (HV) of the heat-affected zone;

(d) range of hardness (HV) in the weld metal;

(e) reference to this test method, (i.e., AS 1085.20, section G4, appendix G).

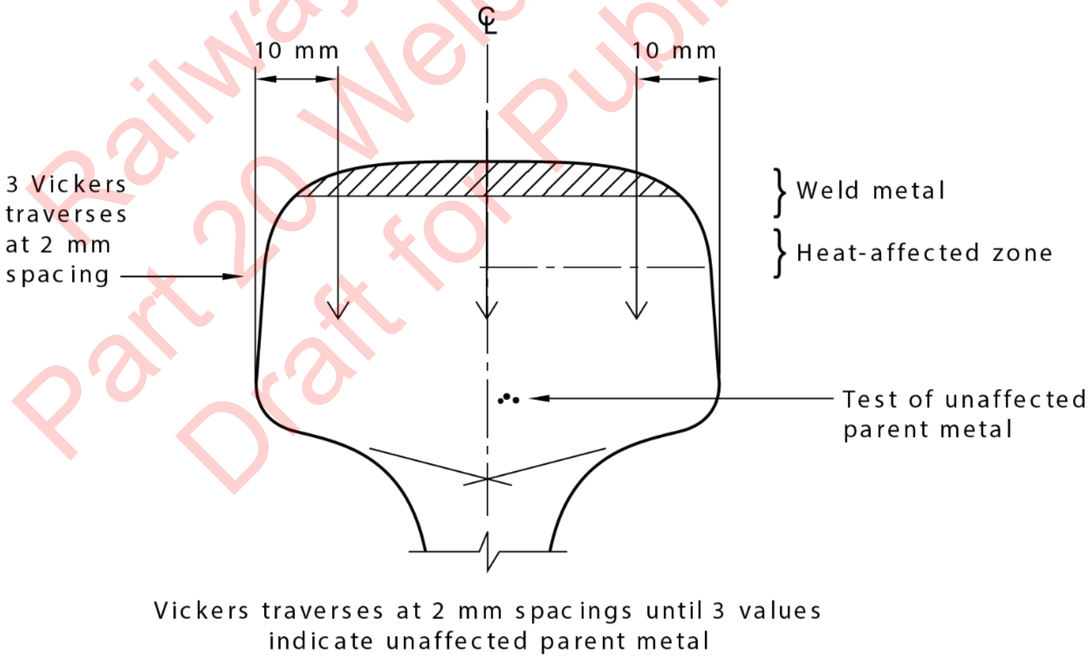


Figure G.5 Hardness traverse down from top

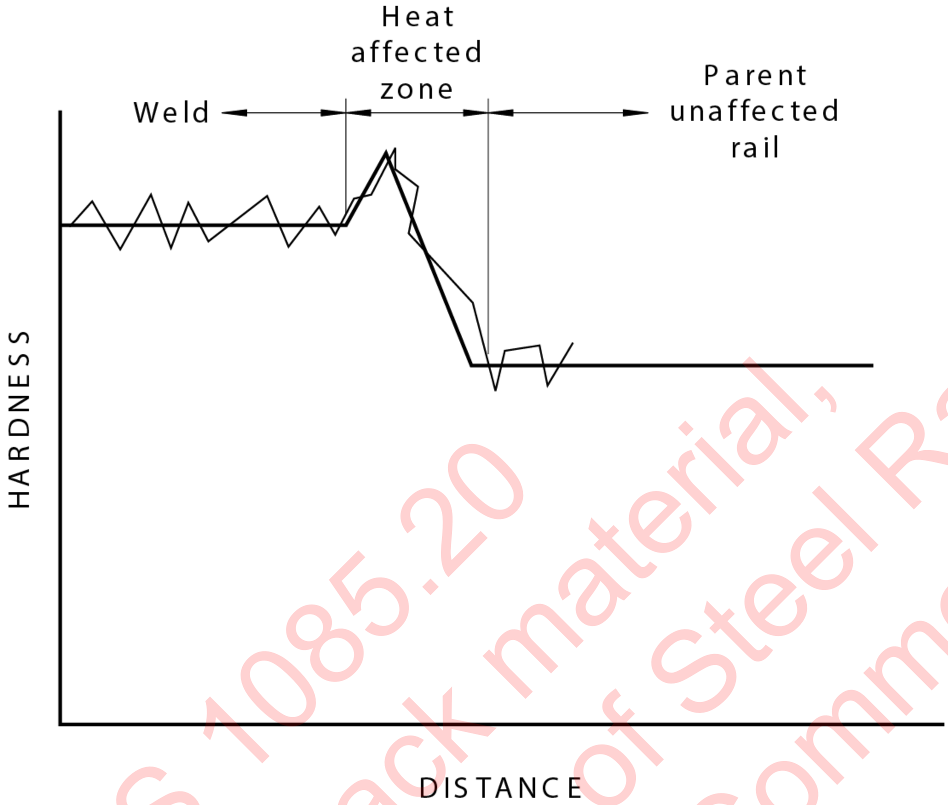


Figure G.6 Typical hardness profile

Appendix H Macroscopic tests

(Normative)

H.1 Scope

This appendix sets out the methods for macroscopically testing welds.

H.2 Fusion zone – shape and dimensions

H.2.1 Procedure

The procedure shall be as follows:

(a) Section the weld longitudinally along the centre-line of the welded rail so as to include the entire heat-affected zone on both sides of the weld for at least 20 mm (see figure H1 for flash butt welds and figure H2 for aluminothermic welds).

(b) Wet grind the specimen in successive stages on the appropriate polishing machine. The stages of abrasive used can vary depending on the type of material being prepared. The grinding operation shall be performed under coolant or continuous water flow. Final grinding shall be done with 1200 grit papers or finer.

(c) Perform a macroscopic test (by etching) in accordance with AS 2205.5.1.

(d) For FBW measure the angle of the bond line and visible HAZ perpendicular to the rail foot. For the HAZ, the angle may be measured to the widest or narrowest part of the HAZ from the rail foot. The first 5mm from the head and foot should be excluded.

H.2.2 Records

The following shall be recorded:

(a) The symmetry of the shape of the fusion zone.

(b) The total width of the Heat affected zone (X_{vhaz}) at the head, centre of web and foot.

(c) For flash butt welding, the symmetry and straightness of the bond line and HAZ.

(d) For aluminothermic welding, the minimum width of the zone between end of the rail and fusion boundary between parent rail and weld portion (xf).

(e) The presence of any defects including electrode, slag or contact burns, cracks, lack of fusion, inclusions, porosity.

NOTES:

1. For aluminothermic welding, measurement of x_f may be made using datum lines marked on each rail prior to welding.

2. For flash butt welding, the fusion zone is regarded as a line (bond line) and xf is not measured.

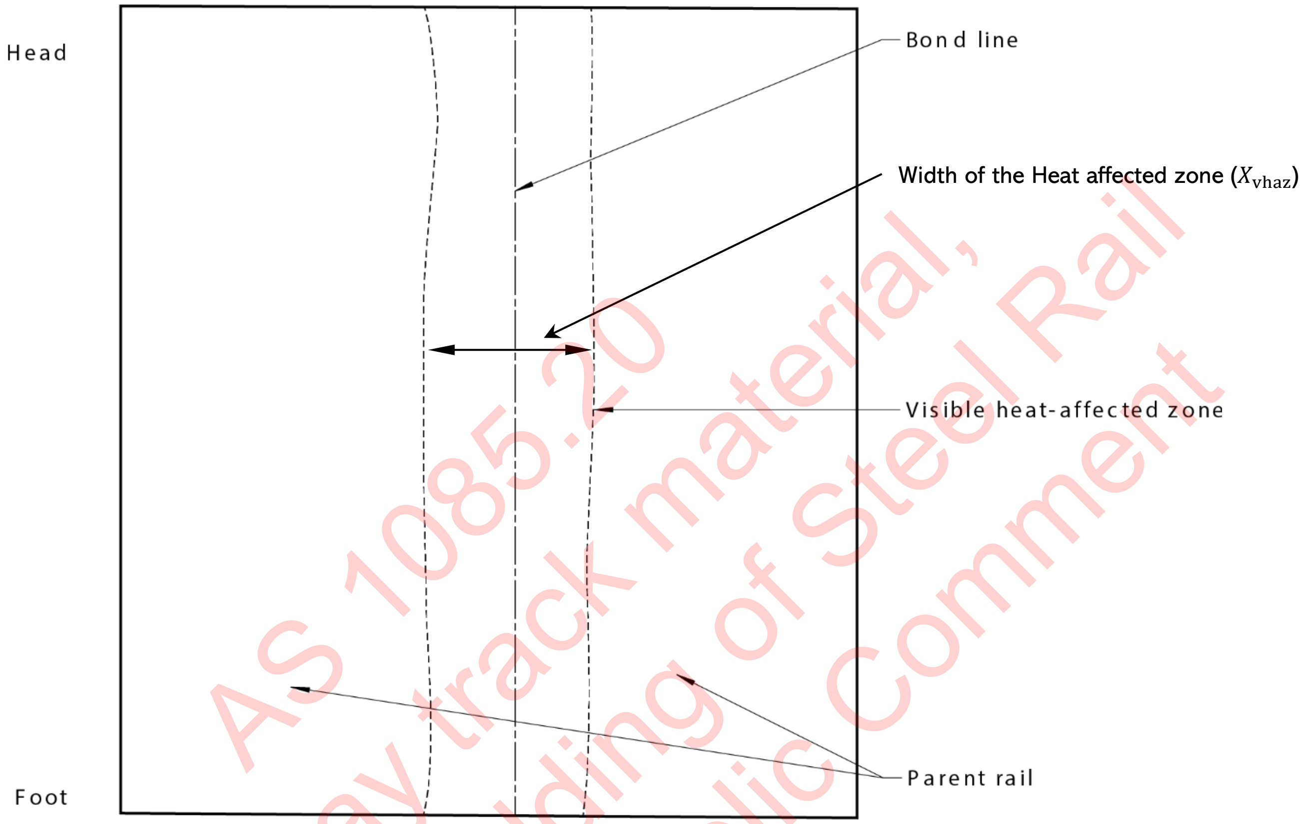


Figure H.1 Shape of fusion zone in flash butt weld

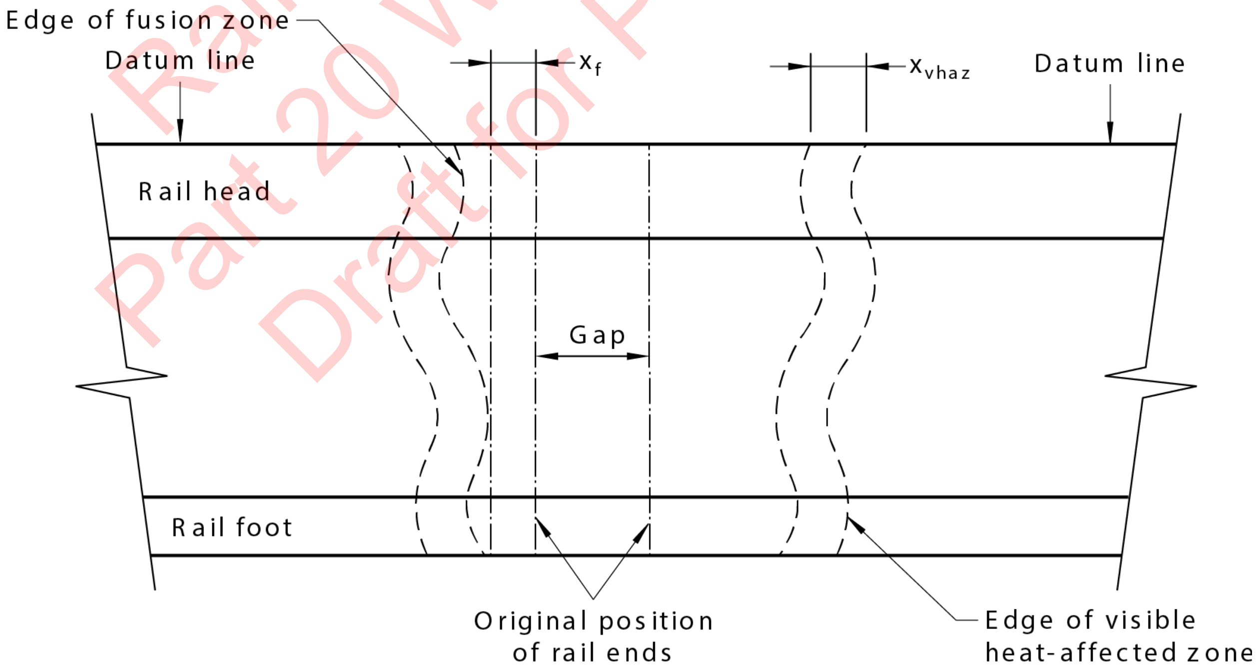


Figure H.2 Shape of fusion zone in aluminothermic weld

H.2.3 Report

The following shall be reported:

(a) Date of testing and name of testing facility.

(b) Identification of the samples.

(c) Any lack of symmetry of the fusion zone.

(d) The minimum width of the fusion zone (xf).

(e) Lack of fusion.

(f) Presence of slag inclusions, porosity.

(g) Any other defects.

(h) Photograph of macro sample with legible scale bar shall be included.

(i) Reference to this test method, i.e. AS 1085.20, section H2, appendix H.

H.3 Visible heat-affected zone – running surface

H.3.1 Procedure

The procedure shall be as follows:

(a) Prepare the running surface of the rail for a macroscopic test and perform the test (including etching) in accordance with AS 2205.5.1.

(b) Measure the width of the visible heat-affected zone (see figure H2) on the rail running surface centre-line.

Appendix I Microscopic test

(Normative)

I.1 Scope

This appendix sets out the method for microscopically testing welds.

I.2 Procedure

The procedure shall be as follows:

(a) Section the rail and examine areas as shown in Figure I1 for flash butt welds and Figure I2 for aluminothermic welds. Each sample taken is to:

i. have a minimum of 5 mm of material visible on either side of the bond line.

ii. extend at least 3 mm beyond the visible heat-affected zone, and

iii. be at least 22 mm in depth, from the running surface or foot.

(b) For flash butt welds, additional samples may be prepared from other positions of interest in the visible heat affected zone such as at any other locations where evidence of anomalous microstructures is present in the macro-etched section at the longitudinal centreline of the rail.

(c) At a combination of two rail grades, both sides of the weld at the head and foot shall be examined.

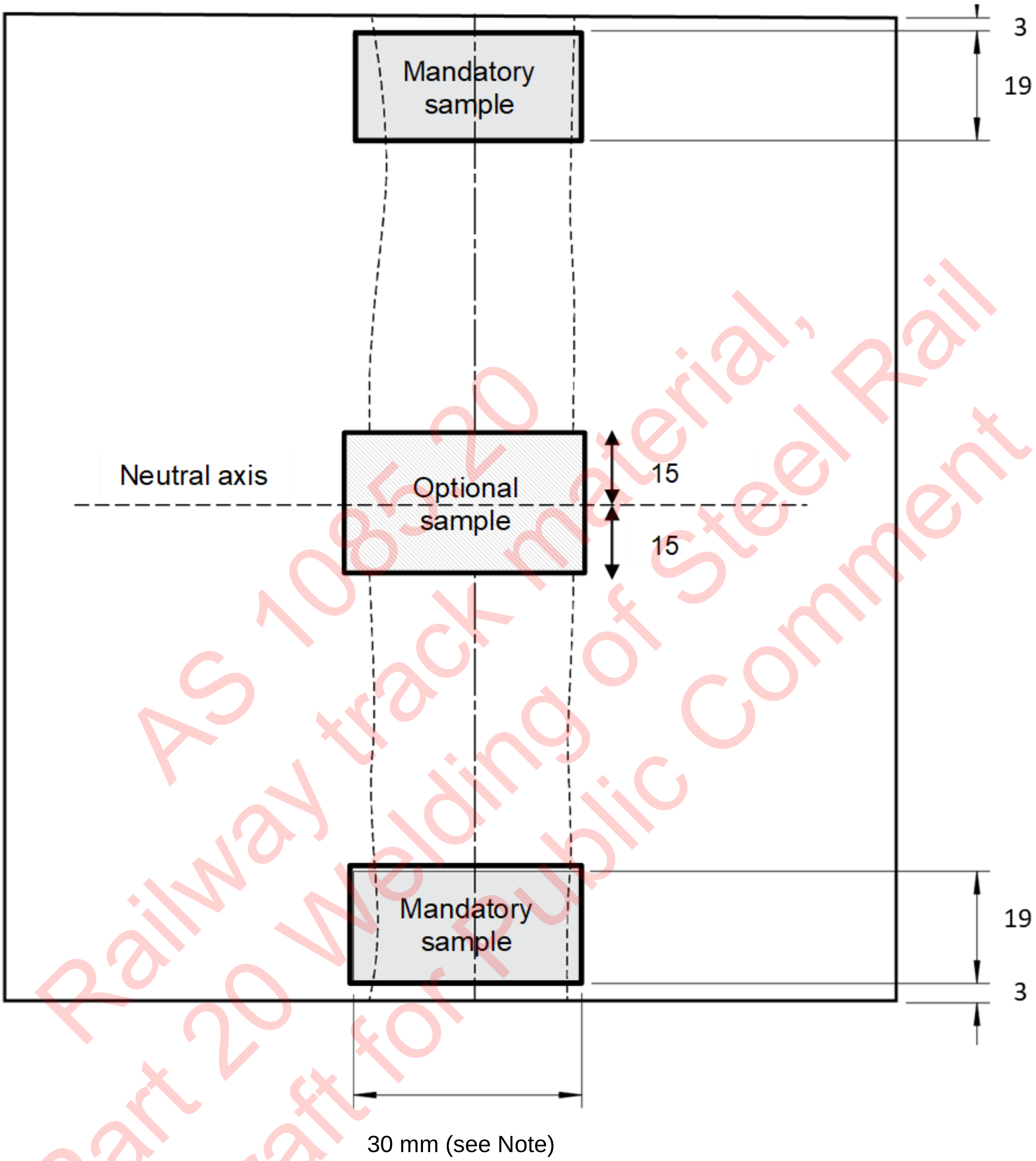
(d) prepare and etch the samples in 2% Nital (i.e., nitric acid in ethanol) or similar.

(e) examine using a metallurgical microscope at x 100 magnification, to determine the microstructure of the fusion zone and the heat-affected zone of the parent rail. Higher magnifications may be used for identification of microstructural constituents.

(f) Quantify the amount of untempered martensite in each of the designated areas by measuring the area fraction in the worst field of view ($1mm^2$) at 100x magnification.

(g) Measure the width and length of the largest cluster of Grain boundary carbides

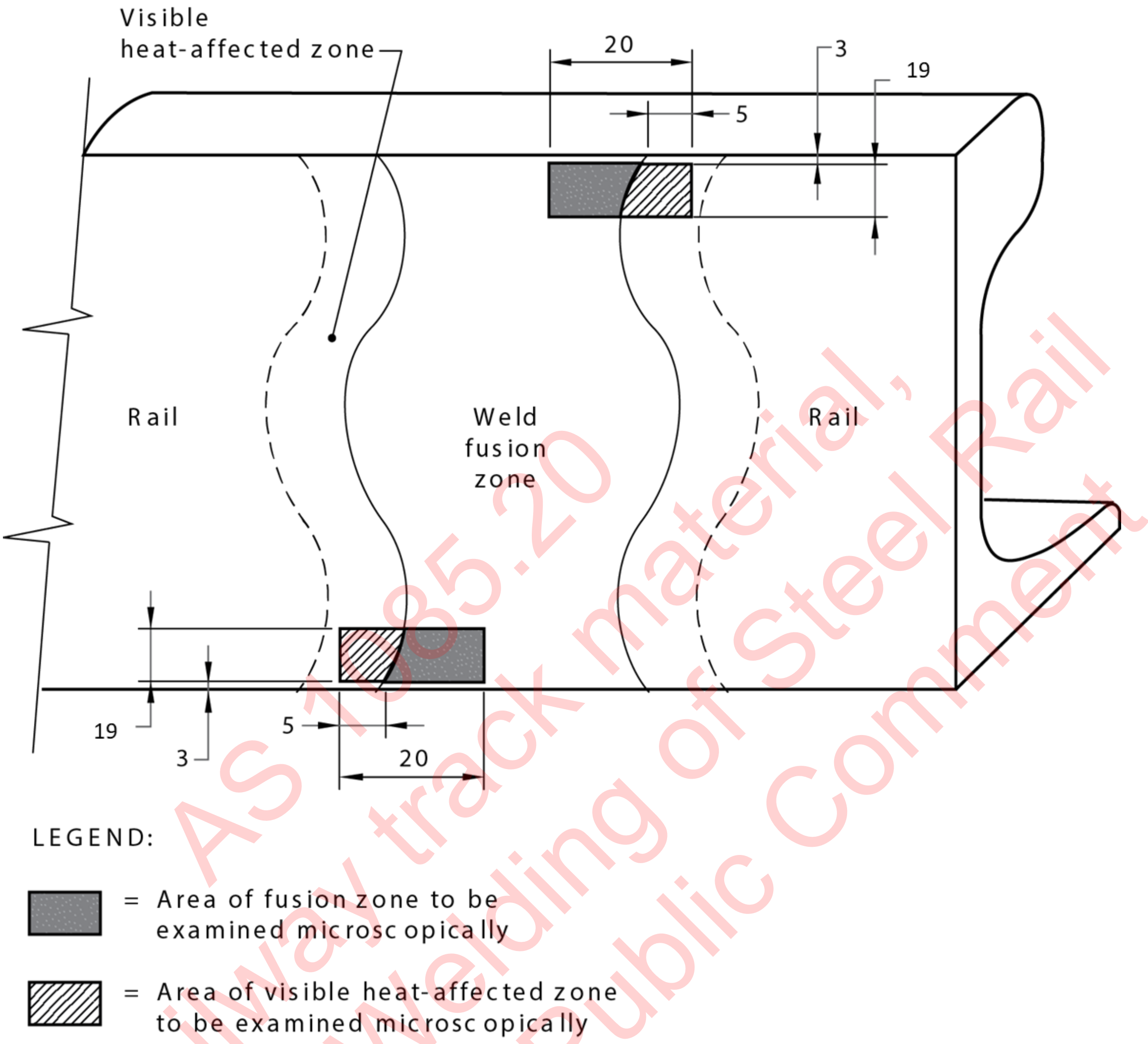
NOTE: The intent of this examination is to identify the presence of microstructure which can have a detrimental influence on the performance of the welds. Some individual rail grades may contain a segregated region containing higher concentrations of some elements along the centreline of the web and lower head. This region can have a higher tendency to develop martensitic microstructures during flash butt welding. Such locations can be evident as darker or lighter etching than that associated with a pearlitic microstructure.



(Dimensions in millimetres)

Figure I.1 Scheme for taking samples for microscopic examination – flash butt weld

NOTE: Sample width is to cover entire visible heat affected zone on both sides of the weld for mixed rail types. For welds with wider visible heat-affected zone, sample may be offset such that designated zone extends across bond line and into parent rail on one side only (excluding mixed welds).



(Dimensions in millimetres)

Figure I.2 Scheme for taking samples for microscopic examination – aluminothermic weld

I.3 Report

The following shall be reported:

(a) Date of testing and name of testing facility.

(b) Identification of the samples.

(c) The microstructural constituents present.

(d) Presence and location of cracks, slag, porosity/voids, inclusions, lack of fusion, grain boundary carbides (cementite), ledeburite or any other discontinuities or features.

(e) Photographs of the worst field of martensite, largest grain boundary carbide cluster and any other discontinuities or features listed above shall be included. Photographs shall include a legible scale bar and original magnification.

(f) Reference to this test method, i.e. AS 1085.20, appendix I.

Appendix J Chemical analysis

(Normative)

J.1 Scope

This appendix sets out the sampling method for the chemical analysis of aluminothermic welds.

J.2 Procedure

Conduct a chemical analysis for aluminothermic welds on a sample from the fusion zone within the railhead, at least 5 mm from the transverse centre-line of the weld or on a riser from the weld (see figure J1).

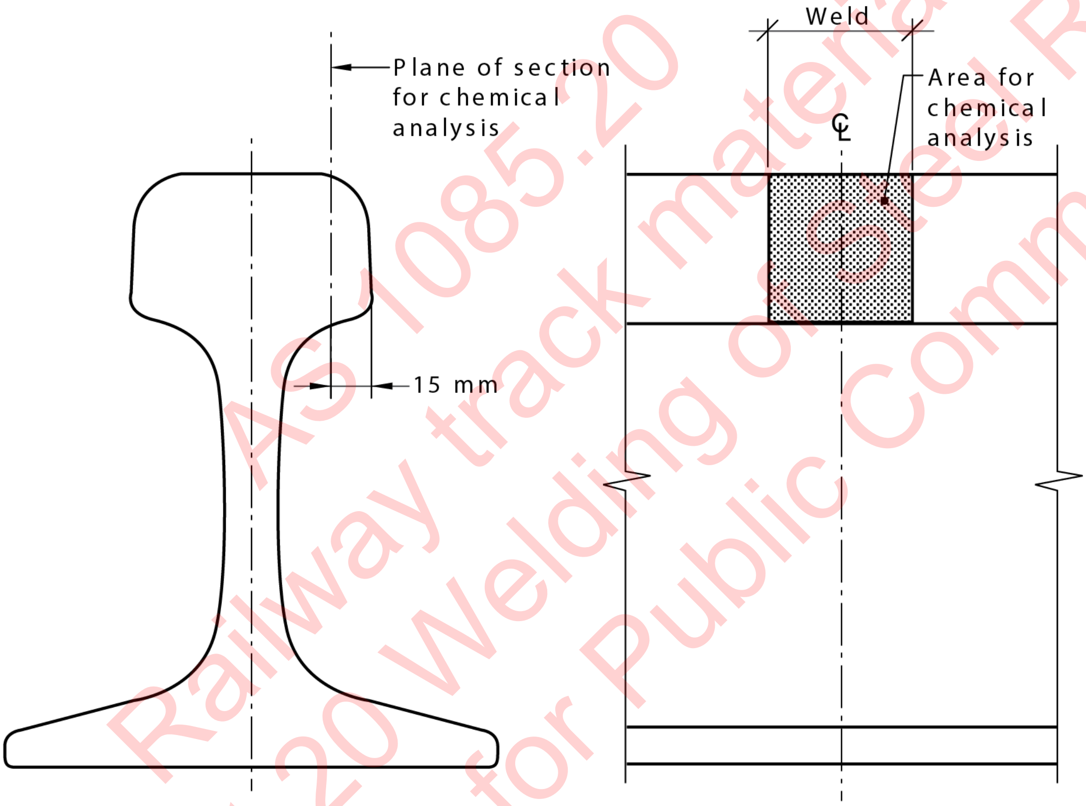


Figure J1 Position for chemical analysis of weld material

J.3 Report

The following shall be reported:

(a) Date of testing and name of testing facility.

(b) Identification of the samples.

(c) The proportions of the elements detected.

(d) Reference to this test method, i.e. AS 1085.20, appendix J.

Appendix K Slow bend test

(Normative)

K.1 Scope

This appendix sets out the method for conducting the static slow bend test for welded rail sections.

K.2 Principle

The welded rail section is subjected to static loading under three point bending conditions so that the foot is placed in longitudinal tension. The load is increased in a controlled manner until the welded rail section fails. The break load and deflection at fracture are recorded.

K.3 Weld samples

The welds shall be provided in a length between 1150 mm to 1200 mm, with the weld at the centre. All weld samples shall be at ambient temperature when tested. If forced air or any other form of cooling is used other than ambient conditions, the cooling method shall be recorded on the test data sheet.

K.4 Apparatus

The following apparatus is required:

(a) Testing stand - structurally rigid stand to be used as a support for the test weld.

(b) Testing device - preferably a hydraulic testing machine, to be used for applying the load at the weld centre-line.

(c) The testing machine shall comply with the accuracy requirements for grade A or grade B testing machines given in AS 2193.

(d) Measuring device - accurate to 0.2 mm, suitable for indicating deflection measurements on the welded rail section.

(e) The testing machine and measuring device shall be calibrated as per AS 2193 and AS 2103 (or other appropriate standard) by an accredited calibrating authority.

Failure of welds tested using this method gives rise to possible impact damage from sections of the failed weld(s), and a short duration and loud noise level. The apparatus shall be designed to restrain the sections of the failed weld(s). Appropriate precautions should be taken to minimize hearing damage to personnel.

K.5 Procedure

The procedure shall be as follows:

(a) Mount the test specimen in the test stand centrally over the specified span width (see figure K.1).

(b) Apply increasing load, in a steady rate in the range 20 to 80 kN/s to the weld centre-line through a thrust piece until failure occurs.

NOTE: At the discretion of the contracting parties, the test may be terminated when the test specimen has exceeded the minimum break load and deflection requirements.

(c) Continuously record the elapsed test period, load and deflection of the rail at mid- span throughout the test until failure. The load and deflection data should be shown graphically throughout the test, as a means of monitoring the test conditions.

(d) Carry out visual inspection of the fracture surfaces.

(e) For rail sizes that do not appear in Table M2, calculate the maximum stress in the foot as follows:

$$\sigma = \frac{PLy_{foot}}{4I}$$

For junction welds, the maximum stress in the foot shall be calculated using the section properties of the smaller of the two rails being joined.

K.6 Assessment of fracture faces

If required, the maximum dimension of any pores, slag inclusions, sand inclusions, lack of fusion or cold shuts that are revealed may be measured and recorded in accordance with Appendix E.

K.7 Report

The following shall be reported:

(a) Date of testing and name of testing facility.

(b) Identification of the samples.

(c) Load, maximum stress in the foot and mid-span deflection at failure.

(d) The type, size and position of any visible imperfections of the fracture face.;

(e) Photographs of the fracture faces and any visual imperfections shall be included.

(f) Reference to this test method, i.e. AS 1085.20, appendix K.

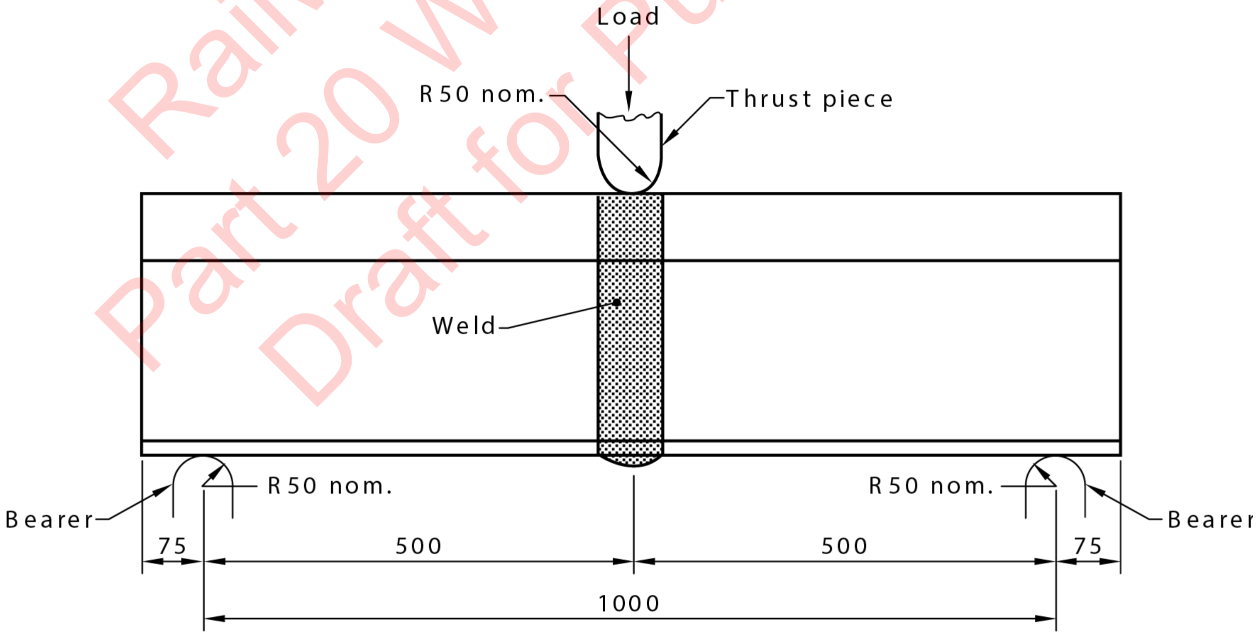


Figure K.1 Typical testing assembly for slow bend test (dimensions in millimetres)

Appendix L Fatigue tests

(Normative)

L.1 Scope

This appendix specifies the methods for fatigue testing of aluminothermic or flash butt welds at the foot and web of the welded rail section.

L.2 Fatigue test for foot of welded rail section

L.2.1 General

Qualification of aluminothermic welds to this test method shall normally be undertaken in accordance with the requirements for the 'past-the-post' method.

An alternative test method (the 'staircase' test) that may be used for determining the fatigue strength of the foot of a welded rail section over the specified number of loading cycles is also described.

L.2.2 Principle

The fatigue performance is measured in terms of the nominal outer fibre stress range in the foot of the weld, that is, the stress range that would exist in the parent rail at the weld location in the absence of the weld. The relationship of the applied load to the nominal outer fibre stress is established using a separate, strain-gauged test piece made of plain rail of the profile under consideration.

L.2.3 Apparatus

Tests shall be conducted in four-point bending with the rail foot in tension. The inner span shall be a minimum of 150 mm plus the weld collar width under the rail foot. The outer span shall exceed the inner span by at least twice the rail height and shall be symmetrical about the inner span. See Figure L1 for a typical testing assembly.

The inner and outer spans shall be measured and recorded.

The distances from the centre-line of the actuator to the loading points shall be measured and recorded. Corresponding dimensions on either side of the actuator centre-line shall not differ by more than 3 mm.

The radius of curvature of the loading points shall be in the range 40 mm–60 mm. The loading point contact surfaces shall be free to translate or rotate so that friction between the loading points and the specimen is minimized.

The testing machine shall comply with the accuracy requirements for grade A or grade B testing machines given in AS 2193.

NOTE: A 1000 kN actuator is likely to be suitable for most applications.

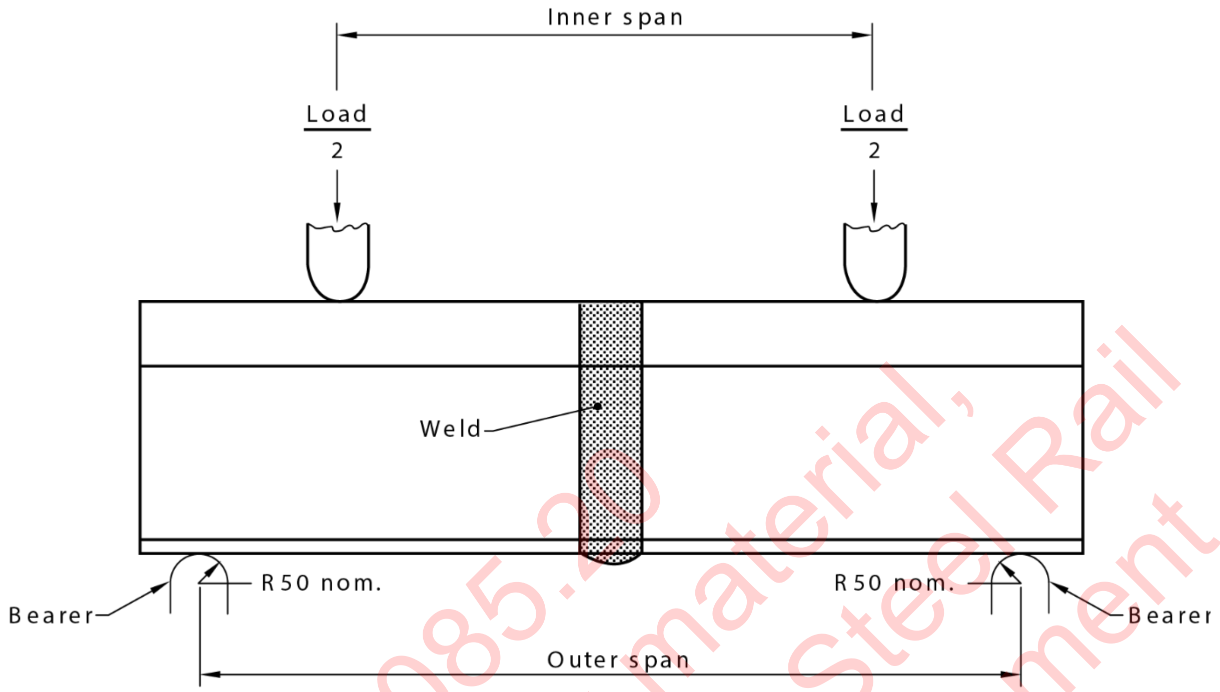


Figure L..1 Typical testing assembly for foot fatigue test (note r = Radius)

L.2.4 Determination of stress to load relationship

L.2.4.1 Test pieces

The test pieces shall be sections of new rail of the profile being examined, with a length exceeding that of the outer span of the test rig by at least 50 mm. For junction welds (of different rail sizes), the rail profile used to establish the load versus stress relationship shall be the smaller of the two profiles.

L.2.4.2 Procedure

The relationship between the nominal outer fibre stress in the test piece and the applied load shall be established as follows:

(a) Attach strain gauges to the foot of the rail.

(b) load the test piece to a significant proportion of the elastic capacity of the rail section;

(c) derive a relationship for stress as a function of applied force on the basis of a linear relationship.

The test pieces shall be clamped using an appropriate method for the test equipment used. As the clamping force can affect the relationship between applied force and outer fibre stress, the clamping arrangements used during the procedure outlined in this Section shall be identical to those to be used during fatigue testing.

L.2.5 Test pieces for foot fatigue testing

Test pieces shall be produced by joining two rail sections using the weld to be tested. The weld shall be positioned at the centre of the test piece to within ±10 mm. The test piece length shall not exceed the outer test span by more than 100 mm.

L.2.6 Fatigue test procedure

The procedure shall be as follows:

(a) Position a test piece in the test rig so that the centre-line of the weld is aligned with the centre-line of the actuator to within 3 mm.

(b) Apply the maximum force corresponding to the specified (past-the-post test) or required (staircase) outer fibre stress.

(c) Cyclically load the weld by applying the force outlined above. The cycling frequency shall not exceed 10 Hz. The indicated maximum load and load range shall be maintained to within 2% of the nominal value required. Continue cycling until either the test piece breaks or 3 000 000 cycles have been applied.

L.2.7 Past-the-post test

L.2.7.1 Principle

The ‘past-the-post’ method measures the fatigue performance of the foot of a welded rail section at a specified outer fibre stress applied for 3 000 000 cycles.

L.2.7.2 Fatigue test procedure

The procedure shall be as described in section L2.6, with the additional requirements described below:

(a) The maximum load shall produce an outer fibre stress of 230 MPa.

(b) Three welds shall be tested.

L.2.8 Staircase fatigue test (optional, see section L2.1)

L.2.8.1 Principle

The ‘staircase’ method establishes the fatigue strength of the foot of a welded rail section at an endurance of 3 000 000 cycles. The fatigue strength is measured in terms of the nominal outer fibre stress range in the foot of the weld, that is, the stress range that would exist in the parent rail at the weld location in the absence of the weld.

L.2.8.2 L2.8.2 Fatigue strength procedure

The procedure shall be as described in paragraph L2.6, with the additional requirements described below:

(a) Estimate the maximum force corresponding to the mean fatigue strength of the weld at 3 000 000 cycles when the ratio of the minimum to the maximum cycle load is 0.1.

NOTE: Where no other information exists, a reasonable assumption would be that the mean fatigue strength at 3 000 000 cycles corresponds to a nominal cyclic outer fibre bending stress range of approximately 260 MPa.

(b) Cyclically load the weld by applying the force estimated above. Continue cycling until either the test piece breaks or 3 000 000 cycles have been applied. If the test piece breaks, the test result shall be recorded as a ‘failure’. If it survives, it shall be recorded as a ‘run-out’. The cyclic force range shall also be recorded.

(c) Where the test results in a run-out, repeat the test on another test piece using a cyclic force range corresponding to a nominal outer fibre stress in the foot 20 MPa above that in the first test. Where the test result is a failure, repeat the test on another test piece with a cyclic force range corresponding to 20 MPa below that in the first test.

(d) Continue testing until either one of the following occurs:

i. results are available for at least 3 stress range levels with results of both types, that is, both a failure and run-out obtained at an intermediate test level. Ten results shall be obtained;

ii. at least 6 consecutive results are obtained, which alternate between failure and run-out at two neighbouring stress levels.

L.2.8.3 Data analysis

Determine the mean value (m) and standard deviation (s) of the fatigue strength using the following equations, by determining first whether failures or run-outs are the less frequent events:

Equation L1

$$m = S_0 + d([A\ /\ N] \pm 0.5)$$

Equation L2

$$s = 1.62d(0.029 + (BN - A^2)\ /\ N^2),\ \text{but} \geq 5.3\ \text{MPa}$$

(In cases where the calculated value of the standard deviation is less than 5.3 MPa, the standard deviation is small and will be deemed acceptable.)

where

$[(A\ /\ N) + 0.5]$ is used if the less frequent event is a run-out; and

$[(A\ /\ N) - 0.5]$ is used if the less frequent event is a failure.

Example calculation:

This example shows the analysis of data from a fatigue strength determination using the staircase method. Results are given in the Table L1 and the calculations below.

The lowest stress range at which a failure occurs (S_0) is 220 MPa. As failure is the less frequent event, the form of Equation L2 to be used is as follows:

$$m = S_0 + d([A/N] - 0.5)$$

$$= 220 + 20([4/4] - 0.5)$$

$$= 220\ MPa$$

The standard deviation (Equation L3) is as follows:

$$s = 1.62d(0.029 + (BN - A^2)\ /\ N^2)$$

$$= 1.62\ \times 20\ (0.029 + (24 - 16)\ /\ 16)$$

$$= 17.1\ MPa$$

Table L.1 Typical test results

Test load (s)	**Test number**											**Calculations**				
	1	2	3	4	5	6	7	8	9	10	11	Lowest load with failure	i	n_i	$i\ n_i$	$i^2\ n_i$
260			x										2	1	2	4
240		0		x				x					1	2	2	2
220	0				x		0		0			S_0	0	1	0	0
200						0										
D = 20 MPa												$N = \Sigma\ (n_i)$		4		
Failures (x): 4 – less frequent event run-outs												$A = \Sigma\ (i\ n_i)$			4	
(0): 5												$B = \Sigma\ (i^2\ n_i)$				6

L.2.9 Assessment of fracture faces

If required, the maximum dimension of any pores, slag inclusions, sand inclusions or cold shuts that are revealed may be measured and recorded in accordance with section E4 of appendix E.

L.2.10 Report

The following shall be reported:

(a) Date of testing and name of testing facility.

(b) Identification of the samples.

(c) The test method used (‘past-the-post’ or ‘staircase’).

(d) The inner and outer spans.

(e) The distances from the centre line of the actuator to the loading points.

(f) For the ‘past-the-post’ test, the number of cycles completed for each of the test welds.

(g) For the ‘staircase’ test:

i. the mean fatigue strength;

ii. the standard deviation of the fatigue strength.

(h) If required, type, size and position of any imperfections found.

(i) Reference to this test method, i.e. AS 1085.20, section L2.7, appendix L.

L.3 Fatigue test for web of welded section (optional)

L.3.1 Principle

This test method may be specified where there is an increased risk of weld failure as a result of torsional loading on the rail web, for example as a result of eccentric wheel-rail contact conditions or high lateral forces under the service conditions. The weld rail section is subjected to fatigue-loading conditions whereby a vertical load is applied at a location towards one edge of the rail head to produce vertical bending stresses in the rail web. Sufficient vertical load is applied to produce the maximum bending stresses under the service conditions for which the welds are intended.

L.3.2 Testing conditions

The following need to be defined by agreement between the contracting parties:

(a) Maximum vertical test load that will produce the maximum vertical bending stress at the web. Lateral movement of the rail head should not be constrained.

(b) Support spacing. A value of 200 mm is recommended.

(c) Value of eccentricity (E) that defines the point of application. A value of 22.5 mm is recommended for 68 kg/m rails.

In general, the test load will be equal to the maximum dynamic wheel load obtained under service conditions.

L.3.3 Apparatus

A testing device is required, preferably a servo-hydraulic testing machine, which is capable of:

(a) supporting the specimen centrally over the specified span width, as shown in figure L2;

(b) applying a minimum vertical load equal to 0.0 kN, or as near to this value as possible, but not greater than 10 kN;

(c) allow for lateral movement during loading of the rail to avoid unduly constraining the rail;

(d) applying the maximum vertical test load at the eccentricity (E) on the railhead of the specimen; and

(e) applying the required minimum and maximum vertical loads in a cyclic manner for a duration of 3 x 10 cycles, (unless otherwise agreed between the purchaser and the supplier)

NOTE: See figure L2 for a typical test assembly.

The testing machine shall comply with the accuracy requirements for grade A or grade B testing machines given in AS 2193.

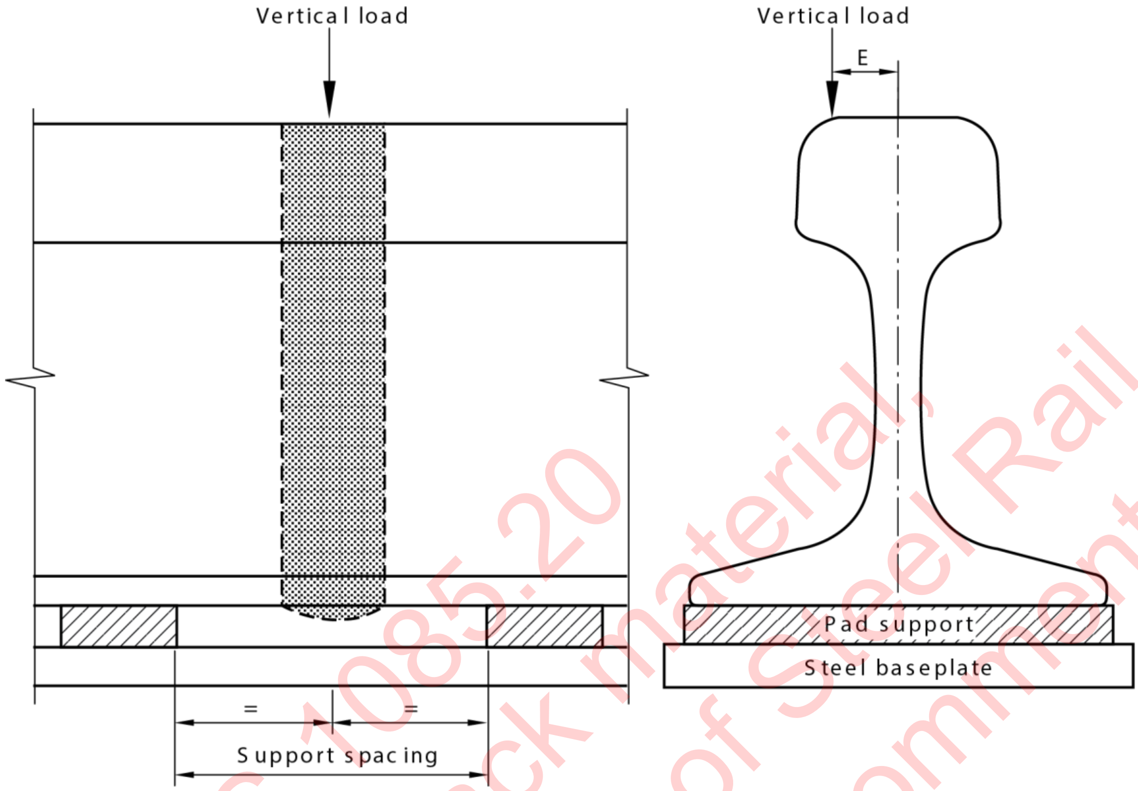


Figure L.2 Typical assembly for the fatigue testing of web of welded rail

L.3.4 Procedure

The procedure for fatigue testing the web of a welded rail section shall be as follows:

(a) Mount the test specimen in the testing device so that it is located over the specified support span width (see Figure L2(a)) or continuously supported (see Figure L2(b)).

(b) Restrain the test specimen by means of clamps or other fixing devices on the rail foot of the specimen.

(c) Apply to the test specimen 3 x 10^6 cycles of loading between the minimum vertical load and the maximum vertical load through a hardened steel ball or other means to simulate point load (if necessary, a small indentation may be machined into the railhead to locate and adequately restrain the load applicator) to the edge of the railhead. The load shall be applied at the bond line of flashbutt welds, or at the centre of the fusion zone of aluminothermic weld. The cyclic loading shall be applied at a loading frequency between 5 Hz and 10 Hz.

NOTE: A higher loading frequency may be used, provided it can be demonstrated that the requirements regarding the control of the minimum and maximum vertical loads are satisfied.

L.3.5 Report

The following shall be reported:

(a) Date of testing and name of testing facility.

(b) Identification of the samples.

(c) Minimum and maximum vertical applied test loads.

(d) Number of test cycles and loading frequency.

(e) Any fatigue cracks that occur.

(f) If required, position and size of any imperfections found.

(g) Reference to this test method, i.e. AS 1085.20, section L2, appendix L.

Appendix M Qualification of a flash butt welding procedure

(Normative)

M.1 Scope

This Appendix defines the qualification of a flash butt welding procedure.

M.2 General requirement

Qualification of a flash butt welding procedure shall be undertaken using welds produced in accordance to the documented welding procedure.

M.3 Testing for qualification and requalification

M.3.1 General

Qualification of the flash butt welding process, as specified in the welding procedure, shall be in accordance with the tests set out in this appendix. Failure of any test will cause non- compliance for rail profiles being tested.

Separate qualification is required for each rail profile and each rail material grade.

Tests for qualification shall be as set out in Table M.1.

Table M.1 Flash butt welding – number of tests required for qualification

Test	Test method (Appendix)	Number of samples tested
Surface examination – Visual	E	All
Surface alignment	E	All
Weld Collar tolerances	E	All
Non-destructive testing 1. Internal imperfections 2. Magnetic particle inspection	F	All
Hardness test Weld heat-affected zone and bond line Width of heat-softened zone	G	2
Macroscopic test Visual heat-affected zone width (xvhaz) Weld heat-affected zone and bond line angle	H	2
Microscopic test Bond line, decarburization Heat-affected zone microstructure	I	2
Slow bend test	K	3
Web Fatigue Test	L3	Optional (3)

M.3.2 Qualification for junction and step welds

This Standard does not cover junction or step welds made by flash butt welding.

M.3.3 Preparation and allocation of test welds

The number of test welds required for the tests referred to in table M.1 shall be produced in accordance with the welding procedure and allocated randomly.

Three consecutive test welds must be produced for slow bend test.

The number of each test shall be in accordance with the appropriate parts of Table M.1.

Where any of the slow bend tests fail to meet the required test criteria, retesting using a new set of three welds for the slow bend tests is required. Where other tests fail to meet the required test criteria as a result of an imperfection or imperfections in the rail, retesting shall be made on a one-to-one basis.

M.3.4 Qualification of flash butt welding procedure

A flash butt welding procedure for a particular rail profile and material grade shall be qualified by passing the tests specified in Table M.2.

Table M.2 Test requirements for qualification of flash butt welding

Test	Test method (appendix)	Description	Pass criteria	
Visual inspection	E	Visual inspection of all surfaces	No cracks, tears, gouges, shear drag, electrical contact burns, grinding burns	
		The maximum grinding deviation with respect to rail surface profile: 1. Top of railhead 2. Side of railhead	 -0.0 mm, +0.15 mm -0.0 mm, +0.3 mm	
Surface alignment tolerances	E	Tolerance grade (Note 1)	Vertical	Horizontal
		AT1	-0.0 mm, +0.3 mm	±7 milliradians (Note 2)
		AT2	-0.0 mm, +0.5 mm	±0.5 mm
		AT3	Limit to be specified by the purchaser	Limit to be specified by the purchaser
Welded collar tolerances – Deviations from rail profile	E	At rail web and upper side of rail foot	-0.0, +2 mm	
		Underside of rail foot	-0.0, +1.0 mm (Fixed plant welder) -0.0 to 2.0 mm (Mobile flashbutt welder)	
Non-destructive test	F	Internal imperfections	Railway owners should determine the limits for internal imperfections. Suitable values are given in table Appendix F.	
		Magnetic particle inspection	2 mm maximum linear indication	

Test	Test method (appendix)	Description		Pass criteria	
Hardness traverse	G (Section G3)	Rail type		Deviation of the average re-austenitised Zone from parent material (excluding the bond line) in Vickers hardness	
		As-rolled rail		±40 to a maximum of 380 HV	
		Head-hardened rail – air quenched		-30, +60 to a maximum of 50 HV above parent rail hardness	
		Combination of different rail grades		±20 HV from average hardness of the two parent rails to a maximum of 50 HV above parent rail hardness	
		Width of head-softened zone (Dimension AB)		On either side of the weld, less than or equal to 20 mm	
Macrostructure	H	Weld head-affected zone and bond line		Perpendicular to rail foot ±5°	
		Heat-affected zone (x_{yhaz}) at the head, centre of web and foot.		25 to 50 mm	
Microstructure	I	In designated zones within weld heat-affected zone and bond line Clause appendix I)		Microstructure should be substantially pearlitic in all assessed areas. The maximum allowable length of micro cracks and voids is 0.10mm in any of the assessed areas. The maximum allowable area fraction of martensite in the worst field (1 mm^2) must be less than 5% in the head and foot area at x100 magnification. If the web is assessed, the maximum at the web is less than 8%. The maximum allowable vertical length of a cluster of grain boundary cementite (GBC) in the head and foot area is 1mm. If the web is assessed, the maximum vertical GBC in the web is 3mm. (This excludes GBC in the secondary HAZ spheroidised regions). The presence of ledeburite is not acceptable in any of the assessed areas.	
		Width of decarburization at the bond line		Maximum 1.0 mm	
Slow bend test	K	Rail size (kg/m)	Deflection	Load	Condition of fracture face
		50	25 mm (min)	965 kN (min)	No lack of fusion or entrapped slag
		60	20 mm (min)	1330 kN (min)	
		68	12 mm (min)	1670 kN (min)	

Test	Test method (appendix)	Description		Pass criteria	
				1900 kN (min)	SC and HH grade high strength grades
		Other	Interpolate from above	exceed 900 MPa max foot stress	
Fatigue test	L	Optional fatigue test for web (Secti L3)		No failure at 3 000 000 cycles	

Notes:

1. The grade is specified for the application. Selection of tolerance level will affect the loads experienced at the weld and thus the expected life of the joint for given track conditions and level of traffic.
2. Note that rail in-track may have a downward deflection due to long term service. In this case, alignment should match the overall rail curvature, and not introduce a local peak. Use of an electronic straightedge is advised to measure and record the final alignment.

The acceptance criteria of slow bend tests for welds between two different rail grades shall be those of the lower strength rail grade (e.g. for the combination of standard carbon and higher strength grades, the standard carbon requirements are applicable).

Appendix N Qualification of an aluminothermic welding procedure

(Normative)

N.1 Scope

This appendix defines the qualification of aluminothermic welding processes used for joining of rails and for head repairs to rails.

N.2 General requirements

Qualification of the welding process shall be undertaken using welds produced in accordance to the documented welding procedure.

The following general requirements apply:

(a) All elements and consumables for a single weld shall be clearly identified. They may be packaged together in kit form except for igniters, which shall be separate.

(b) The aluminothermic welding portion shall be ready for use (that is, pre-mixed and packed in such a way as to prevent segregation during transport).

(c) The mould shall be prefabricated, for the rail profiles to be welded.

(d) The crucible shall be tapped automatically (automatic tapping) and shall have a device to limit spattering.

(e) When used, preheating tools shall be able to operate at ambient temperatures down to 0°C without the need for special precautions.

(f) The process shall be capable of being carried out on track where the maximum rail inclination to the vertical is 1 in 6.

(g) The range of gap shall be limited to ±2 mm, unless stated otherwise on the welding procedure.

N.3 Testing for qualification

N.3.1 General

N.3.1.1 Joining of rails

Qualification of the welding process, as described in the welding procedure, shall be in accordance with the tests set out in this section. Failure of any test will cause non- compliance for the group of rail profiles being tested.

Rail profiles shall be grouped as given in table N1. Separate qualification is required for each rail profile group and each rail material grade.

The testing of welds using the testing regimes given, allows for reduced costs in extending the qualification of a particular weld procedure to other rail sizes and types, (i.e., head- hardened, see AS 1085.1).

Tests for qualification are set out in section N.3.2 to N.3.5 and Table N.2. The process of testing is given in section N.3.6.

Table N.1 Rail profile groups

Group	Rail profile (AS 1085.1) kg
0	68
1	60
2	53
3	50, 47
4	41, 31

N.3.1.2 Head repair welds

Qualification of the welding process, as described in the welding procedure, shall be in accordance with the tests set out in this section.

Tests for qualification are set out in Table N.7.

N.3.2 Qualification for group 1 rails (60 kg)

Qualification of a weld for group 1 rails (60 kg rail, see table N.1) shall be by passing the tests given for testing regime 1 as given in table N.2. The weld to be qualified shall be as described on the welding procedure.

N.3.3 Qualification for rails in other groups

To extend qualification from tests done using testing regime 1 to another rail profile (group of profiles, see table N.1), further testing shall be carried out in accordance with testing regime 2 given in table N.2.

N.3.4 Qualification for other types of rail

To extend qualification from tests done using testing regime 1 to another type of rail (e.g. head-hardened within the same group, see table N.1) further testing shall be carried out in accordance with testing regime 3 given in table N.2.

N.3.5 Qualification for junction welds

Qualification for junction welds should be as for standard welds. Testing regimes are specified in section N.3.2, N.3.3 and N.3.4.

The outer fibre stress at failure for junction welds shall be calculated using the section properties for the smaller of the two rails.

Table N.2 Aluminothermic welds for joining of rails – number of tests required for qualification

Test	Test method (appendix)	Testing regime		
		1 (Initial qualification)	2 (Extension to other groups)	3 (Extension to other types)
Surface examination – visual (as cast and ground)	E	All	All	All

Test	Test method (appendix)	Testing regime		
		1 (Initial qualification)	2 (Extension to other groups)	3 (Extension to other types)
Non-destructive test 1. Internal imperfections 2. Magnetic particle / Penetrant inspection	F	All	All	All
Hardness test – running surface	G (section G2)	6	6	6
Hardness test – width of head-softened zone	G (section G3)	2	2	2
Macroscopic test - Visible head-affected zone	H (section H2)	2	2	2
Fusion zone shape and dimensions	H (section H3)	2	2	Nil
Microscopic test -		2	Nil	2
Fusion zone Head-affected zone	I	2	Nil	2
Chemical analysis	K	3	Nil	3
Slow bend test	K	6	2	2
Fatigue test	L	3	1	1

N.3.6 Preparation and allocation of test welds

The number of test welds required for the tests referred to in table N.2 shall be produced in accordance with the welding procedure.

The welds required for fusion zone shape and dimensions shall be produced to give 3 welds at the minimum and 2 welds at the maximum of the initial range of welding gap (that is, 3 welds at nominal gap less 2 mm and 2 welds at nominal gap plus 2 mm).

Welding gap shall be measured after weld alignment (peaking) at the running surface, web mid-point and foot tips. The maximum gap is the maximum distance measured at any of the points and the minimum gap is the minimum of any of these points.

All laboratory welds should be subjected to the non-destructive test procedure given in section F.3 of appendix F. If any welds show a response, they shall be included in the fatigue test.

Any test welds allocated to the fatigue test, as a result of non-destructive testing, shall not be tested at the lowest load and, therefore, shall not be introduced into the test sequence until this has been established. If the cause of the ultrasonic response is not apparent following fatigue testing and inspection, further investigation shall be made to try to establish the cause. Otherwise, welds shall be allocated to the tests randomly.

The number of each test shall be in accordance with the appropriate parts of tables N.2 and N.3.

Where tests fail to meet the required test criteria as a result of an imperfection or imperfections in the rail, retests shall be made on a one-to-one basis.

N.3.7 Qualification of aluminothermic welding process

N.3.7.1 General

An aluminothermic welding process for a particular rail profile group and material grade shall be qualified by passing the tests given in table N.3.

Table N.3 Test requirements for qualification of aluminothermic junction welds

Test	Test method (Appendix)	Description	Pass Criteria
Visual inspection - Surface examination	E	As-cast weld surface	See section N3.7.2, appendix N
		Ground weld surface	See section N3.7.3, appendix N
Non-destructive test	F	Internal imperfections	Railway owners should determine the limits for internal imperfections, width of heat-softened zone, fracture face imperfections and width of fusion zone (as appropriate). For internal imperfections, suitable values are given in, appendix F.
		Magnetic particle inspection	2 mm maximum linear indication
Weld hardness (HBW)	G (paragraph G2)	Weld centre-line	As-rolled rail: 280 ±20 HBW
		Weld centre-line	Head-hardened rail: 360 ±20 HBW
Hardness traverse	G (paragraph G3)	Max fusion zone hardness	430 HV
		Shape of the hardness graph	A nominally symmetrical shape about the centre of the weld (except at welds between two different rail grades)
		Width of heat-softened zone (Dimension AB, See paragraph G3.2(k))	On either side of the weld, less than or equal to one of the following widths (see note): 20 mm 30 mm 40 mm
Macroscopic tests (etched)	H	General	No lack of fusion; presence of slag inclusions, porosity
Fusion zone	H	Shape	A nominally symmetrical shape about the longitudinal and transverse axes
		Width of fusion zone (xf)	Min. 3 mm
Visible heat-affected zone - Running surface	H	Visible heat-affected zone—Running surface (xvhaz) (See Paragraph H3.2(d))	Less than or equal to one of the following widths (see note): 20 mm 30 mm

Test	Test method (Appendix)	Description	Pass Criteria
			40 mm
Microscopic tests	I	In fusion zone	No bainite or martensite
		In heat-affected zone	No bainite or martensite
Chemical analysis	J	Composition	See paragraph N3.7.4, appendix N
Slow bend test	K	Stress in the foot at failure	750 MPa (min.)
		Fracture face imperfections	(See note)
Fatigue	L	Fatigue test for rail foot (paragraph L2.7)	No failures at 3 000 000 cycles
		Fatigue strength for rail foot (paragraph L2.8)	Mean ±standard deviation ≥210 MPa
		Fracture face imperfections (foot fatigue tests)	(See note)
		Optional fatigue test for web (paragraph L2.9)	No failure at 3 000 000 cycles

N.3.7.2 As-cast weld surface

Following stripping and final grinding, the as-cast weld collar surface shall be visually examined for fusion zone soundness. Any imperfections shall conform to the following:

(a) there shall be no cracks with surface length of 2 mm, or greater;

(b) there shall be no pores with a dimension greater than 3 mm, nor shall there be more than three pores in the size range 2 mm - 3 mm per test piece excluding the flashing;

(c) slag or sand inclusions shall conform to all the limits given in Table N.4. Any imperfections shall remain within the collar, i.e., not intrude into the rail cross- section, and shall not touch the edge of the weld collar to rail intersection.

Table N.4 Maximum dimensions of slag or sand inclusions

Surface dimension (max) mm	Depth (max) mm
10	3
15	2
20	1

N.3.7.3 Ground weld surface

The finished ground surface of the head (including the weld collar surface on either side of the railhead) shall comply with the following:

(a) There shall be no cracks.

(b) In an area of 2 mm diameter, associated with the lower edge of the railhead and weld collar (see figure E2), there shall be no more than two welds out of the number required for the tests defined in the appropriate testing regime shall contain a maximum of one pore, slag or sand inclusion with a maximum dimension of 1 mm to 2 mm.

(c) With the exception of the above, there shall be no pores or other volume imperfections greater than 1.0 mm.

N.3.7.4 Chemical analysis of weld metal

The maximum and minimum concentration of each element shall be specified in the welding procedure. When tested in accordance with appendix J, the results shall fit within the ranges set out in table N.5. The working range shall be within the permitted range.

Table N.5 Limits for chemical analysis of the weld metal

Element	Rail grade	Permitted range (limits to all products)		Working range (limits for a particular product – within the permitted range) %
		Min	Max	
Carbon	As-rolled,	0.40	1.0	-
	head-hardened	0.50	1.0	-
Silicon	All	0.00	1.20	±0.25
Manganese	As-rolled,	0.50	1.40	±0.20
	head-hardened	0.50	1.60	±0.20
Phosphorus	All	0.00	0.035	—
Sulphur	All	0.00	0.030	—
Chromium	As-rolled,	0.00	0.20	-
	head-hardened	0.00	0.80	
Molybdenum	All	0.00	0.40	-
Nickel	All	0.00	0.10	-
Aluminium	All	0.02	0.60	±0.20
Copper	All	0.00	0.20	-
Tin	All	0.00	0.02	-
Titanium	All	0.00	0.05	-
Noibium	All	0.00	0.01	-
	As-rolled,	0.00	0.10	-

Element	Rail grade	Permitted range (limits to all products)		Working range (limits for a particular product – within the permitted range) %
		Min	Max	
Vanadium	head-hardened	0.00	0.40	-

N.4 Testing for requalification

N.4.1 General

Approval for changes to an already qualified procedure shall be made following the limited testing set out in table N6. The degree of the change shall be the variation from the values given in the original qualification.

Table N6 identifies the tests to be performed when changes fall within the limited testing range of variation. Changes greater than the numeric values set in the limited testing range of table N6 shall require full qualification as given in paragraph N.3.

For any process modification that requires a non-destructive test or slow bend test (appendix F or K), the results of the evaluation shall be the same as or better than the appropriate part of the original evaluation.

A single process variation or change may involve any combination of the parameters specified in table N6. Parameters may be changed repeatedly in new variants or changes using the 'limited testing' ranges given in table N6, provided the value is not outside the range when compared to the original qualification.

A process shall be tested as it will be used, that is, independently tested changes shall not be combined without further testing.

N.4.2 Parameters

The parameters for determining a change to the process listed in table N.3 are defined as follows (see figure N1):

(a) Mould collar and riser, where the dimensions of W, D, d and cross-sectional areas of risers are to be nominal dimensions taken from the drawing of the model (pattern) used to produce the moulds (a similar drawing is required for the changed process):

  i. Weld collar width (W).

  ii. Collar depth (D1 and D2).

  iii. Collar depth (d1 and d2).

  iv. Riser cross-section - in foot (Rf).

  v. Riser cross-section - in neutral axis (RN).

  vi. Riser configuration - position.

  vii. Riser configuration - numbers.

  viii. Any changes in the chemical nature of the main component of the refractory.

(b) Crucible system:

i. any changes in the chemical nature of the main component of the refractory;

ii. any changes in the initial internal crucible geometry outside the supplier’s drawing.

(c) Tapping system:

i. the refractory of the tapping system body;

ii. any changes in the geometry of the tapping system body outside the supplier’s drawing;

iii. all changes to the releasing mechanism.

(d) Preheating system:

i. any changes outside the defined critical parameters and equipment used in the preheating chain will require testing.

ii. any change of preheating fuels (oxidizing or reducing) will require testing.

iii. any change in working pressure or preheating times outside the ranges originally specified will require testing.

(e) Portion changes in the weight outside of the production tolerances given by the supplier and changes in the ranges of elements specified.

(f) Welding gap change of the range of gap outside the ±2 mm. Testing shall cover each end of the new range of gap not covered by the original testing.

NOTE: For measurement of the gap, see section N2(g).

Table N.6 Testing required for limited changes

Process variants	Range outside which limited testing is required	Limited testing following changes (test methods as defined in table N1)					
		Appendices					Other tests
		G, (paragraph G2)	K	E, F (see note)	H	J	
Weld collar depth (d1 or d2)	±2 mm			4	4		1 x App L (paragraph L2) fatigue (one staircase)
Weld collar depth (D1 or D2)	±2 mm			4	4		
Weld collar width (W)	±3 mm			4	4		
Riser cross-	±10%			4	4		

Process variants	Range outside which limited testing is required	Limited testing following changes (test methods as defined in table N1)					
		Appendices					Other tests
		G, (paragraph G2)	K	E, F (see note)	H	J	
section - Foot (Rf)							
Riser cross-section - Neut. axis (R_N)	±10%			4	4		
Riser config - Position	±5 mm			4	4		
Riser config-Numbers	All			4	4		
Crucible system	All		6			3	
Tapping system	All		6		4	3	
Preheating system	All	6	6	4	4		2 × paragraph G3 HSZ hardness
Portion	All	6	6	4	4	3	1 × appendix I Microstructure 2 × paragraph G3 HSZ hardness
Welding gap	All	6	6	4	4		2 × paragraph G3 HSZ hardness

Note: the total number of imperfections found should include any found as a result of inspection of the fracture face following the slow bend test or the fatigue test.

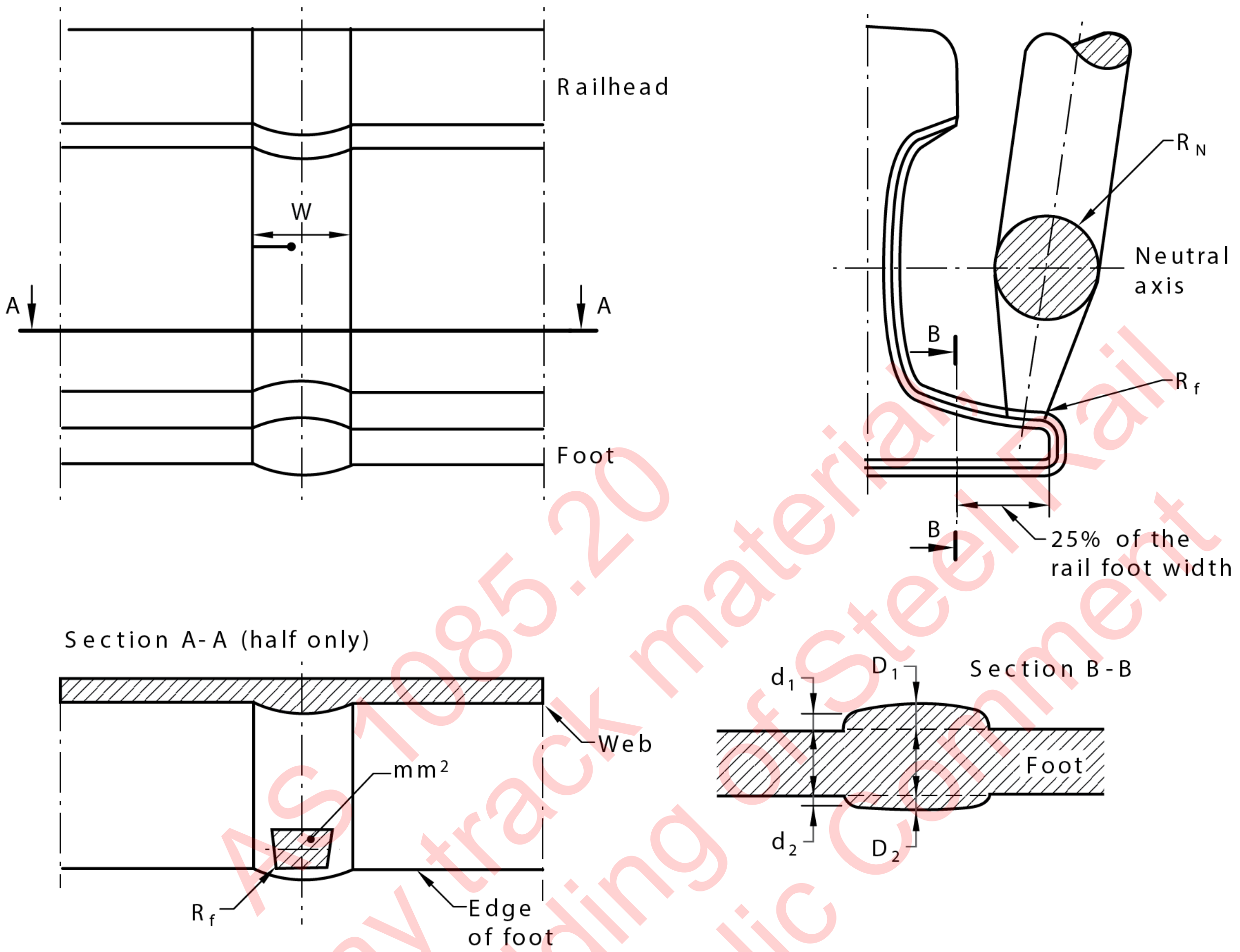


Figure N.1 Process details

N.5 Retest allowance

The production of consumables for aluminothermic welding may be monitored using test welds manufactured for the purpose.

The following tests are typically used:

(a) Visual inspection.

(b) Weld metal hardness test (see Appendix G).

(c) Chemical analysis (see Appendix J).

(d) Slow bend test (see Appendix K).

Other tests, such as ultrasonic testing, may be used.

Where individual test welds fail to meet the specified requirements, retesting may be carried out on additional test welds manufactured using consumables from the same batch according to figure N.2.

Reset allowance

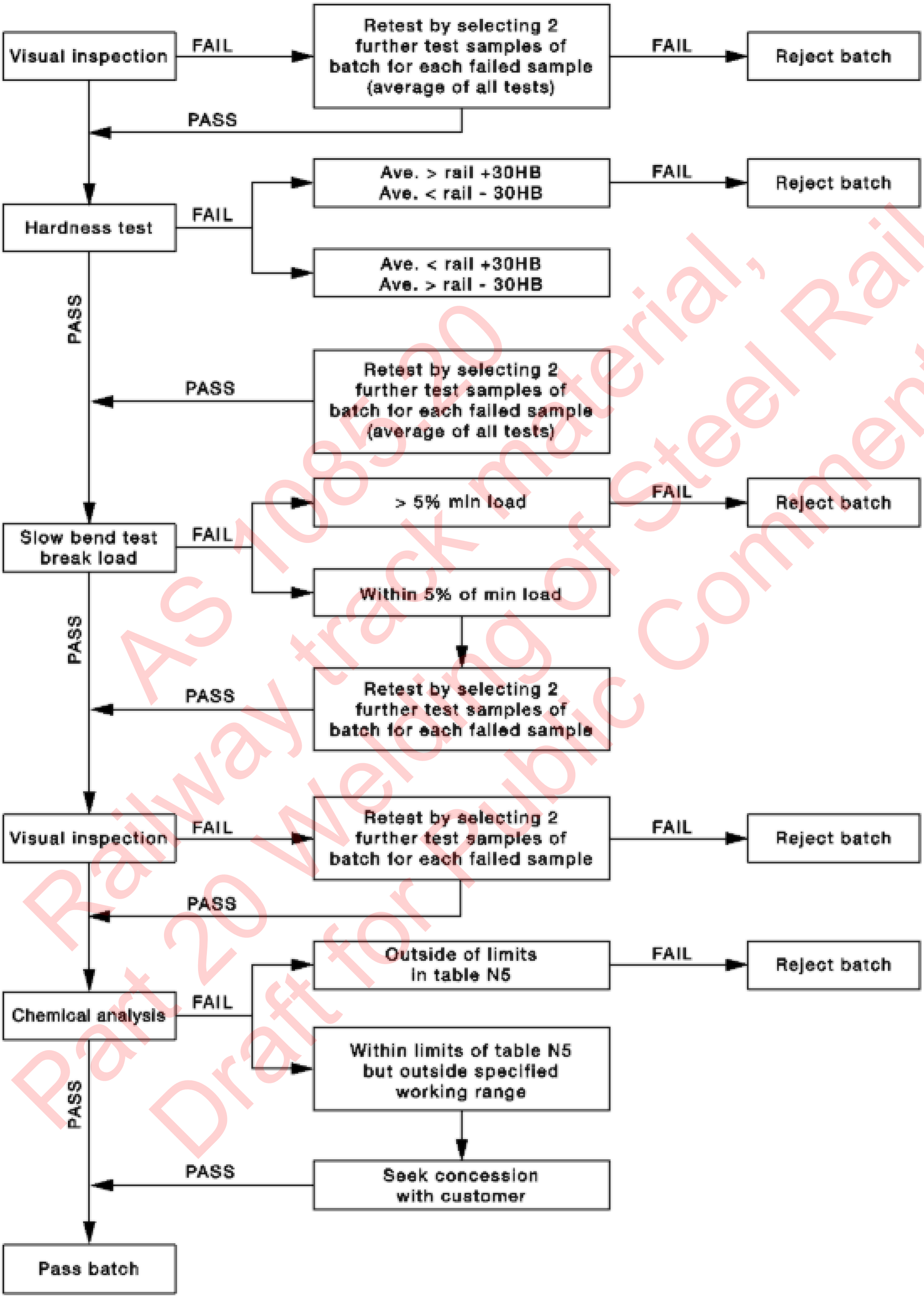


Figure N.2 Retest allowance for batch testing of aluminothermic welds

Table N.7 Qualification of aluminothermic head repair weld

Test	Number of samples	Test method (appendix)	Description	Pass criteria
Visual inspection – surface examination	All 3	E	Ground weld surface	See clause 4.6
Non-destructive test	All 3	F	Internal imperfections	Railway owners should determine the limits for internal imperfections, width of heat-softened zone, fracture face imperfections and width of fusion zone (as appropriate). For internal imperfections, suitable values are given in, appendix F.
			Magnetic particle inspection	2 mm maximum linear indication
Weld hardness (HBW)	All 3	G (paragraph G2)	Weld centre-line	As-rolled rail: 280 ±20 HBW
			Weld centre-line	Head-hardened rail: 360 ±20 HBW
Hardness traverse - vertical	2	G (paragraph G3)	Max weld metal hardness	430 HV
Hardness traverse - longitudinal	2	G (paragraph G3)	Max fusion zone hardness	430 HV
			Shape of hardness graph	A nominally symmetrical shape about the centre of the weld
			Width of heat-softened zone (dimension AB, see paragraph G3.2(h))	On either side of the weld, less than or equal to one of the following widths (see note): 20 mm 30 mm 40 mm
Macroscopic tests	2	H	General	No lack of fusion; presence of slag, porosity
Fusion zone	2	H (paragraph H2)	Shape	A nominally symmetrical shape about the longitudinal and transverse axes
			Width of fusion zone (x_f)	Min. 3 mm
Visible heat-affected zone - running surface	2	H (paragraph H3)	Visible heat-affected zone - running surface (xv_{haz})	Less than or equal to one of the following widths (see note): 20 mm

Test	Number of samples	Test method (appendix)	Description	Pass criteria
			(See paragraph H3.1(b))	30 mm 40 mm
Microscopic tests	1	I	In fusion zone	No bainite or martensite
			In heat-affected zone	No bainite or martensite
Chemical analysis	2	J	Composition	See paragraph N3.7.3, appendix N

Appendix O Qualification of an arc welding procedure

(Normative)

O.1 Scope

This appendix defines the qualification of an arc welding procedure for the repair of a railhead.

O.2 General requirements

Qualification of the welding process shall be undertaken using welds produced in accordance to the documented welding procedure.

O.3 Qualification of welding process

O.3.1 Consumables

Consumables shall be selected that best match the hardness of the rail being welded.

O.3.2 Qualification tests

Qualification of the welding process, as described in the welding procedure, using the recommended welding consumables, shall be in accordance with the tests set out in this paragraph.

A series of 3 test welds shall be performed and tested as set out in table O1. The welds shall be performed on lengths of new rail and must have 4 layers of weld metal.

The weld length shall be a minimum 150 mm. During welding of the test sample, the rail shall be restrained to simulate constraint in track.

The minimum length of the test sample shall be 1 m.

O.3.3 Qualification of an arc welding procedure

An arc welding procedure for the repair of a railhead, for a particular rail size and material grade, shall be qualified by passing all the tests given in table O.1.

Test	Number of samples	Test method (Appendix)	Description	Pass criteria
Visual inspection - Surface examination	All 3	E	Ground weld surface	See clause 5.7
Non-destructive test	All 3	F	Internal imperfections	Railway owners should determine the limits for internal imperfections (as appropriate). Suitable values are given in Appendix F.
			Magnetic particle inspection	2 mm maximum linear indication

Test	Number of samples	Test method (Appendix)	Description	Pass criteria
Hardness traverse - Vertical	2	G (Paragraph G3)	Max. heat-affected zone hardness	Max. 430 HV
			Weld metal hardness	260 to 420 HV
Gas porosity and slag inclusions ≥ 3 mm diameter	2 (Same as for hardness traverse)	AS 2205.5.1	Cracking, lack of fusion, gas porosity and slag inclusions	None
Microscopic tests	1	I	Fusion zone	No martensite
	1		Heat-affected zone	No martensite

Table O.1 Qualification of metal ARC welding

O.4 Requalification

Requalification shall be carried out for metal arc welding when the following occurs:

(a) Change in the consumable type.

(b) Change in amps of more than 100 %.

(c) Change in voltage of more than 15 %.

(d) Change in welding current from a.c to d.c, and vice versa or a change in d.c. polarity.

(e) Decrease of more than 50 °C in the minimum specified preheat and interrun temperature.

(f) Change in electrode stick-out of more than 20 %.

(g) Change in preheating.

(h) Change in soaking time.

Appendix P Air quenching of flash butt welds

(informative)

P.1 Scope

This Appendix outlines the purpose and guidelines for air-quenching of flash butt welds.

The required post-weld cooling conditions vary with rail grade.

For rail grades requiring forced air cooling (i.e. air quenching) of flash butt welds, the required air quenching conditions (air pressures, commencement time and duration) can vary with the design, condition and configuration of the quenching equipment used.

This Appendix provides guidance on establishing air quenching requirements for different rail grades. These must be verified by qualification testing of welds manufactured using the welding machine(s) and air quenching equipment to be used for production welding.

P.2 Purpose

The purpose of air quenching of flash butt welds is to increase cooling rates in the rail head between the completion of the upset stage and the commencement of the austenite→pearlite transformation. This decreases the temperature at which this transformation occurs.

Reducing the transformation temperature results in a pearlitic microstructure with finer interlamellar spacing, which results in higher hardness levels in the re-austenitised zone and improved resistance to deterioration of the rail surface under traffic.

Air-quenching of flash butt welds is required for head hardened grade rails manufactured to AS 1085.1,and increases the fusion zone hardness to the similar level of hardness in the head of HH grade rails.

Figure P.1 illustrates the effect of air-quenching on the fusion zone hardness of flash butt welds in head hardened grade rails.

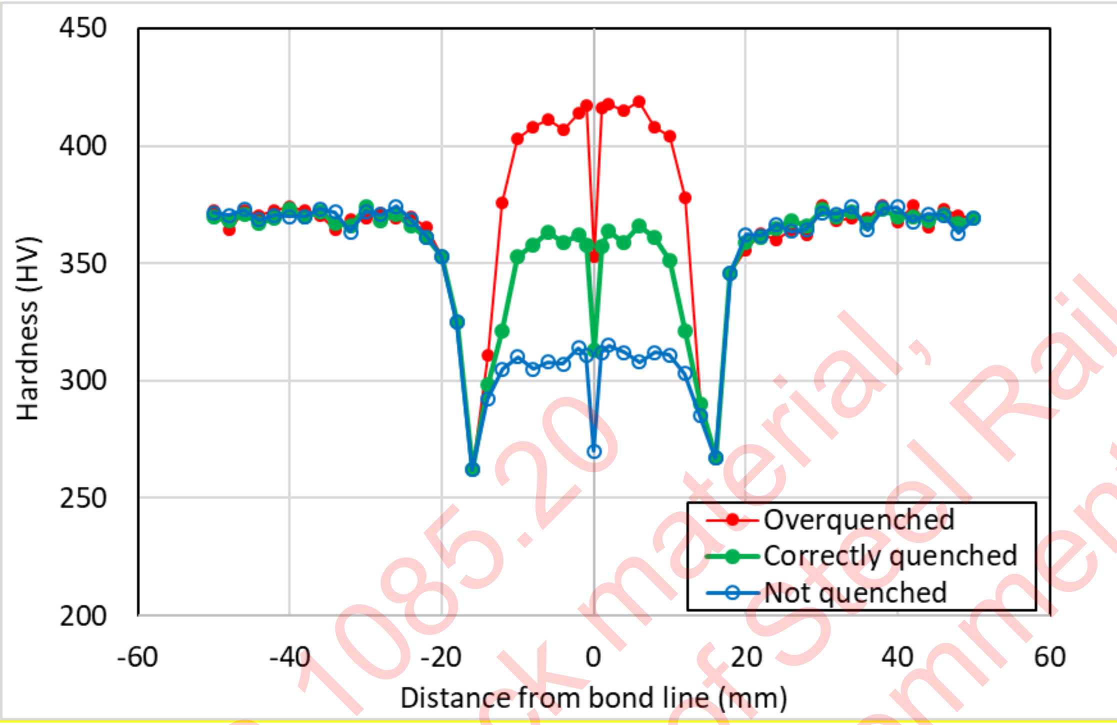


Figure P.1 Hardness distribution in flash butt welds, head hardened rail

P.3 Influence of rail grade

Head hardened grade rails manufactured in accordance with AS 1085.1 require air quenching of flash butt welds as described in Clause P4 and Table xx.

Rail grades manufactured to specifications other than AS 1085.1 can exhibit different transformation characteristics to the AS1085.1 grades. The required post-weld cooling conditions for flash butt welds in such grades may be determined by reference to the continuous cooling transformation (CCT) characteristics of the rail steel. CCT characteristics for such grades shall be supplied by the rail manufacturer.

Flash butt welding procedures, including preheat, upset and post-weld cooling conditions, for rail grades manufactured in accordance with specifications other than AS1085.1 should be reviewed at the time of rail purchase. Welding conditions should subsequently be confirmed by manufacture and assessment of test welds prior to the commencement of production welding.

For a fixed air pressure and volumetric capacity, cooling rates achieved during air-quenching can vary depending on the design and condition of the air-quenching rig, and environmental conditions. Confirmation of the required air-quenching conditions for any new rail welding facility will necessitate manufacture and assessment of test welds during the commissioning stage.

P.4 Air quenching conditions

The recommended air quench conditions for flash butt welded in head hardened grade rails are summarised in Table P.1.

Table P.1 Air quenching conditions for head harden grade rails

Condition	Values
Time from completion of upset to commencement of air-quench:	60 seconds
Duration of quench:	90 seconds
Air quench pressure:	90 psi (620 kPa)
Volumetric capacity of air supply:	Sufficient to maintain the above pressure for the required time. Note that volumetric capacity of the air supply will also depend on the design of the air-quench rig.

Recommended post-weld cooling (air-quenching) conditions for other rail grades manufactured to specifications other than AS 1085.1 such as higher strength premium rails. The quenching conditions should be established carefully based on the recommendations of the rail manufacturers and test results for welds manufactured using the flashbutt welding equipment intended for qualification and production.

For welds in which two different rail grades shall be welded together, the post-weld cooling conditions shall be those which result in the lower cooling rate, i.e. no air quenching should be performed for the welds made from the combination of SC and HH grades.

P.5 Air quenching equipment

Equipment used for air-quenching of flashbutt welds shall be designed and used such that forced air cooling of the underhead region and rail web is avoided.

Positioning of the air-quenching equipment, i.e. within the welding machine, immediately after the welding machine, or one rail length from the welding machine, is dependent on welding cycle times that can be consistently achieved with the welding equipment.

Examples of air quenching fixtures are shown in Figures P.2 to P.4.

Figure P.2: Air-quench rig used in conjunction with fixed flashbutt welding equipment (full head coverage)

Figure P.3: Modified air-quench rig used in conjunction with fixed flashbutt welding equipment

(Restricted air flow to underside of rail head and rail web)

Figure P.4: Air-quench rig used in conjunction with mobile flashbutt welding equipment (top and sides of head only)

Appendix Q Bibliography

The following referenced documents are used by this Standard for information only:

(a) AS 2980 Qualification of welders for fusion welding of steels

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