ARTC

Division / Business Unit: Safety, Engineering & Technology
Function: Track & Civil
Document Type: Manual

Weld Quality Management Manual

ETN-01-06

Applicability

ARTC Network Wide

SMS

Publication Requirement

Internal / External

Primary Source

RTS 3602 Aluminothermic Welding Manual

Document Status

Version #	Date Reviewed	Prepared by	Reviewed by	Endorsed	Approved
1.2	19 Oct 21	Standards	Stakeholders	A/Manager Standards	A/General Manager Technical Standards 27/10/2021

Amendment Record

Amendment Version #	Date Reviewed	Clause	Description of Amendment
1.0	07 May 20	All	First issue of manual.
1.1	15 Jun 21	5	Updated rail weld geometry parameter names
		Table 4	Updated Pandrol 8mm step weld kit from pending approval to approved for use
		6	Added reference to Section 1 Rail for guidance on the remedial action to take for rail weld defects
		All	Editorial and format updates
1.2	19 Oct 21	3	Addition of Thermit 80Ib/40ACR Welding Kit

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1 Introduction

1.1 Purpose

The purpose of this manual is to summarise the requirements of rail welding on the ARTC network. It provides guidance to welders on a process that gives a weld quality with the same life as new rail.

This document features several technical requirements replicated from Section 1: Rail for ease of use. Where there is a conflict between this document and Section 1 the requirement of Section 1 will take precedence.

1.2 Scope

The manual summarises the key Aluminothermic weld quality steps that should be followed to perform a quality weld that meets ARTC reliability and safety requirements. The manual describes the post-weld geometry and visual weld check process that a welder should follow to ensure that their weld meets standards.

1.3 Risks Controlled

This manual is a control for the risk of defective welds that can lead to rail breaks.

1.4 Responsibilities

The persons managing welders and NDT inspectors are responsible for the provision of this manual to staff associated with rail welding

1.5 Parent Procedure

This manual supports the parent procedure:

- Section 1 Rail

1.6 Reference Documents

The following documents support this manual:

- ETE-01-03 Non-Destructive Testing of Rail (for Internal and Surface Defects)
- ETG-01-02 Management of Rail Defects
- Relevant Supplier Manuals

2 Summary of Key Weld Quality Steps (Golden Rules)

Table 1: Key Weld Quality Steps

Step	Requirements
1. Weld Kit Selection	○ Correct weld kit selected for the hardness of rails to be welded. ○ If the two rails to be welded are of dissimilar profile, then a junction weld kit should be used. ○ If the difference in rail heights of the rail to be welded is >5mm then an appropriate step weld kit should be used.
2. Rail End Squareness	○ Rails cut vertically and horizontally square to within ± 2mm.
3. Rail Weld Gap	○ Set the correct rail weld gap, as per supplier's manual, for the rail type and weld process in use. ○ Fasten rail after weld gap is set to prevent movement (scribe mark the parent rail where the rail fasteners closest to the weld gap were placed, check to see if scribe marks have moved prior to weld pour). ○ Cut closure rail on the outside of the guide mark for the cut. ○ Cut parent rail on the inside of the guide mark for the cut.
4. Set-up Rail Peak	○ The rail ends should be peaked to 1.8mm, to set-up place a 1m straightedge with 1.8mm nibs at either end centrally over the weld gap.
5. Mould Alignment	○ The mould must be square and central to the rail in all directions. ○ Shine a torch and look through the mould riser to check that the rail foot is visible and equal on both sides.
6. Sealing the Mould	○ Luting should be thorough to prevent weld metal runout. ○ If there is a gap present between the head of rail and weld moulds, it will be necessary to fit felt. ○ Luting cards should be used to prevent luting putty from falling into the weld gap or riser holes. ○ Do not leave excess luting putty on the top of rail near weld gap, as when shearing takes place this could initiate sand burns.
7. Preheater Torch Criteria	○ Use correct torch type and gas-working pressure (per supplier's manual). ○ Set torch to the correct height, centrally over the weld gap, use a neutral flame and preheat for the correct time (as per supplier's manual).
8. Shearing Criteria	○ After the mould has been removed wait the required time before shearing (as per supplier's manual).
9. Grinding Criteria	○ Perform rough grind that meets ARTC semi-finished weld condition standards (do not grind closer than 1mm to rail head). ○ Perform final grind that meets ARTC finished weld condition standards. The earliest time to perform the final grind is at minimum 1 hour after the rough grind has been completed; it is recommended to wait longer if possible.
10. Geometry and Visual Inspection	○ If defects defined in the relevant ARTC standards occur the weld must be repaired/removed.

2.1 The results of poor execution of Key Weld Quality Steps

Table 2: Related defects to poor execution of key weld quality steps

Key Weld Quality Steps	Related Defects Through Poor Execution
1. Weld Kit Selection	○ This step is critical, as selecting the right type of kit for the rail to be welded will ensure the weld steps to follow are able to be performed to standard.
2. Rail End Squareness	○ Lack of fusion – preheating of rail faces not uniform. ○ Vertical misalignment of the weld collar – moulds not square and central to the rail in all directions. ○ For flame cut rail ends cracks can occur; ▪ If the rails steel grade is not permitted to be flame cut, ▪ If rail bound vehicles pass over the weld gap before the weld has taken place, and ▪ If the weld gap is left for more than 12 hours (4 hours for Head Hardened rail) prior to welding.
3. Rail Weld Gap	○ Porosity – incorrect weld gap width. ○ Slag inclusions – weld gap too wide. ○ Blackholes – incorrect weld gap width. ○ Oxidised/glazed weld – incorrect gap can overheat the rail faces.
4. Set-up Rail Peak	○ Geometry defect (dipped weld) – insufficient peaked height during set-up of the weld geometry.
5. Mould Alignment	○ Porosity – wet moulds, self-tapping thimble releasing too early. ○ Lack of fusion – preheating of rail faces not uniform. ○ Mould inclusions – over rubbing mould recess to rail. ○ Flashing – poor fitting between mould and rail. ○ Finning – overtightening and breaking of the mould. ○ Vertical misalignment of the weld collar – moulds not square and central to the rail in all directions. ○ Lack of collar formation – poor fitting between mould and rail.
6. Sealing the Mould	○ Porosity – wet luting paste. ○ Sand inclusions – luting paste falling into the weld gap. ○ Sand burns - excess debris (luting paste) on top of rail. ○ Flashing – lack of fitness between mould and rail. ○ Lack of collar formation – fitness of mould to rail insufficient.
7. Preheater Torch Criteria	○ Porosity – damp/ wet equipment and materials (i.e. preheat crucible to remove any moisture it may contain if any is known to exist). ○ Lack of fusion – non-uniform preheat of the rail ends. ○ Blackholes – damp/ wet equipment and materials (i.e. preheat crucible to remove any moisture it may contain if any is known to exist). ○ Oxidised/ glazed welds – excessive preheating of the rail faces.
8. Shearing Criteria	○ Hot tear – shearing too early. ○ Sand burns – excess debris (luting paste) on top of rail.
9. Grinding Criteria	○ Geometry defect (dipped welds) – insufficient final grind, too much weld metal removed. ○ Geometry defect (peaked welds) – insufficient final grind, not enough weld metal removed.

2.2 Weld Kit Selection

- The weld kit selected to perform the weld must be suitable for the hardness of rail to be welded.
- If the two rails to be welded are of dissimilar profile, then a junction weld kit should be used.
- If the difference in rail height of the rails to be welded is greater than 5mm than a step weld kit should be used. Table 3 below provides an example of the Thermit step weld kits that are appropriate for welding differences in rail height. The step moulds in Table 3 are for 53kg and 60kg rail, Thermit also supply step weld kits for other rail sizes.

Table 3: Step-weld kit selection guide available for 53kg and 60kg rail sizes (Thermit)

THERMIT	0 – 3mm Rail Wear	>3 – 7mm Rail Wear	>7 – 11mm Rail Wear	>11 – 15mm Rail Wear
Standard Mould	Suitable for use	-	-	-
5mm Step Mould	-	Suitable for use	-	-
9mm Step Mould	-	-	Suitable for use	-
13mm Step Mould	-	-	-	Suitable for use

- Table 4 below provides an example of the Pandrol step weld kits that are appropriate for welding differences in rail height for 60kg rail. Pandrol also supply step weld kits for other rail sizes.

Table 4: Step-weld kit selection guide, available for 60kg rail sizes (Pandrol)

PANDROL	0 – 5mm Rail Wear	>5 – 10mm Rail Wear
Standard Mould	Suitable for use	-
8mm Step Mould	-	Suitable for use

- In tandem with selecting the appropriate weld kit in terms of, type and wear of rail, care must be taken when rubbing the weld moulds to the rail and luting shall be thorough to ensure there are no gaps between weld mould and rail.

2.3 Rail End Squareness Tolerance (± 2mm)

- In preparation of the rail ends to be welded, the cut of both ends must be vertically and horizontally square to within a tolerance of ± 2mm. The cut must be made with the same tool i.e. two flame cut rail ends or two saw cut rail ends to be welded.
- If the cut is not vertically and horizontally square to within a tolerance of ± 2mm, this will make it difficult to align the weld moulds to achieve a vertical weld collar (weld collar vertical alignment should be ± 2mm).
- Non-vertical cut weld gap cannot be inspected post-weld. It can lead to the rail faces not being preheated uniformly and can cause lack of fusion defect due to preheating mis-uniformities. Figure 1 and Figure 2 below illustrates how to measure vertical and horizontal rail end squareness in preparation for a weld, if the rail ends are not square with tolerance, they will not be able to be preheated uniformly, resulting in a lack of fusion defect.

Vertical Rail End Squareness

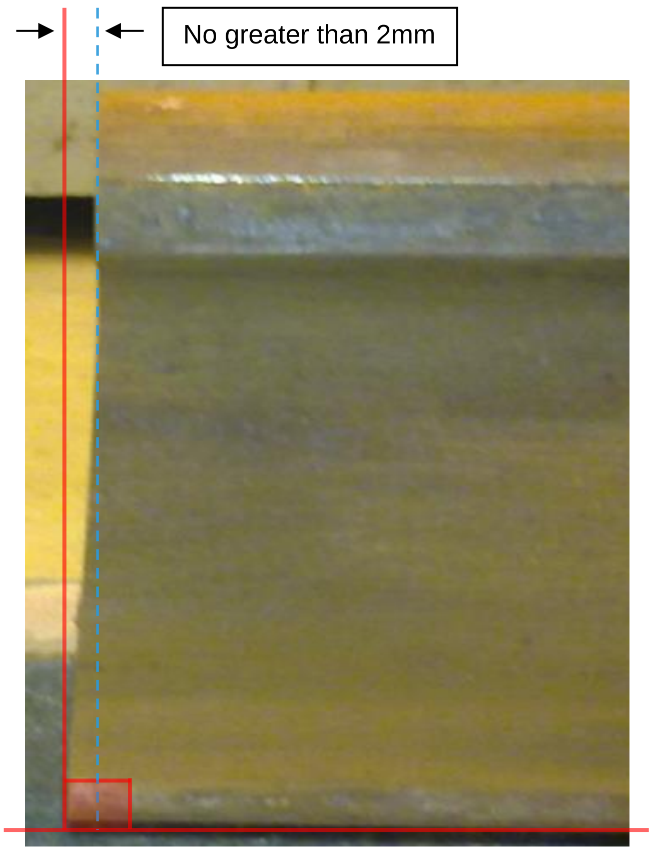


Figure 1: Rail end squareness vertical tolerance should be measured at 90º to the rail foot or head dependant on the angle of the cut and should be no greater than 2mm.

Horizontal Rail End Squareness

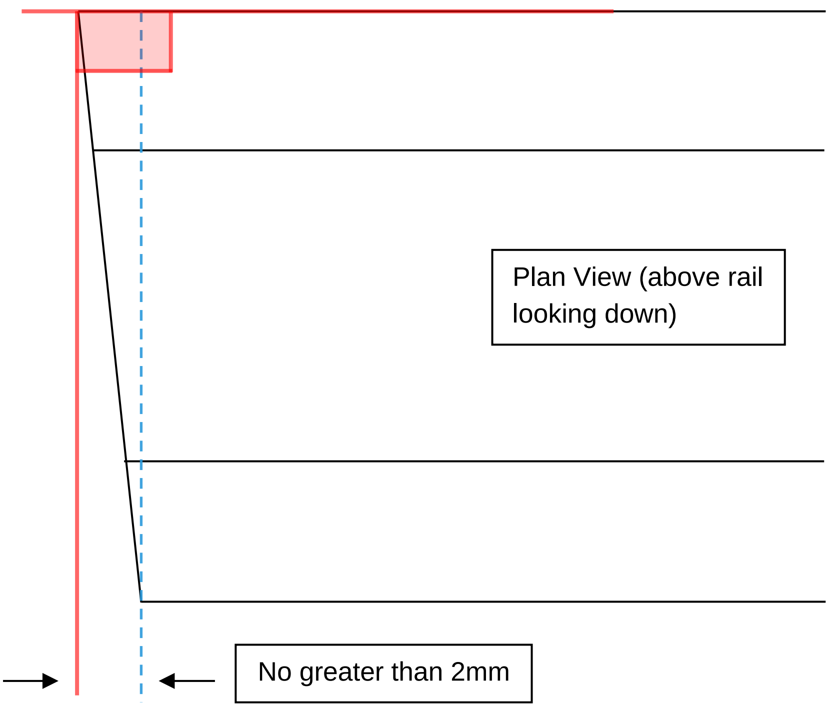


Figure 2: Rail end squareness horizontal tolerance should be measured at 90º to the rail foot either side dependant on the angle of the cut and should be no greater than 2mm.

- The preferred tool to cut the rail weld gap is with a rail saw, rather than a gas flame cutter. If the rail to be welded does have flame cut rail ends;
  - No rail bound vehicle shall pass over the weld gap before welding has taken place.
  - The weld gap shall not be left for more than 12 hours (4 hours for Head Hardened rail) prior to welding, if so, the rail ends must be re-cut immediately removing a minimum steel of 25mm. It is advised to weld the rail in the shortest time possible once it has been cut.

Figure 3 below illustrates rail ends that have been correctly prepared vertically and horizontally square.

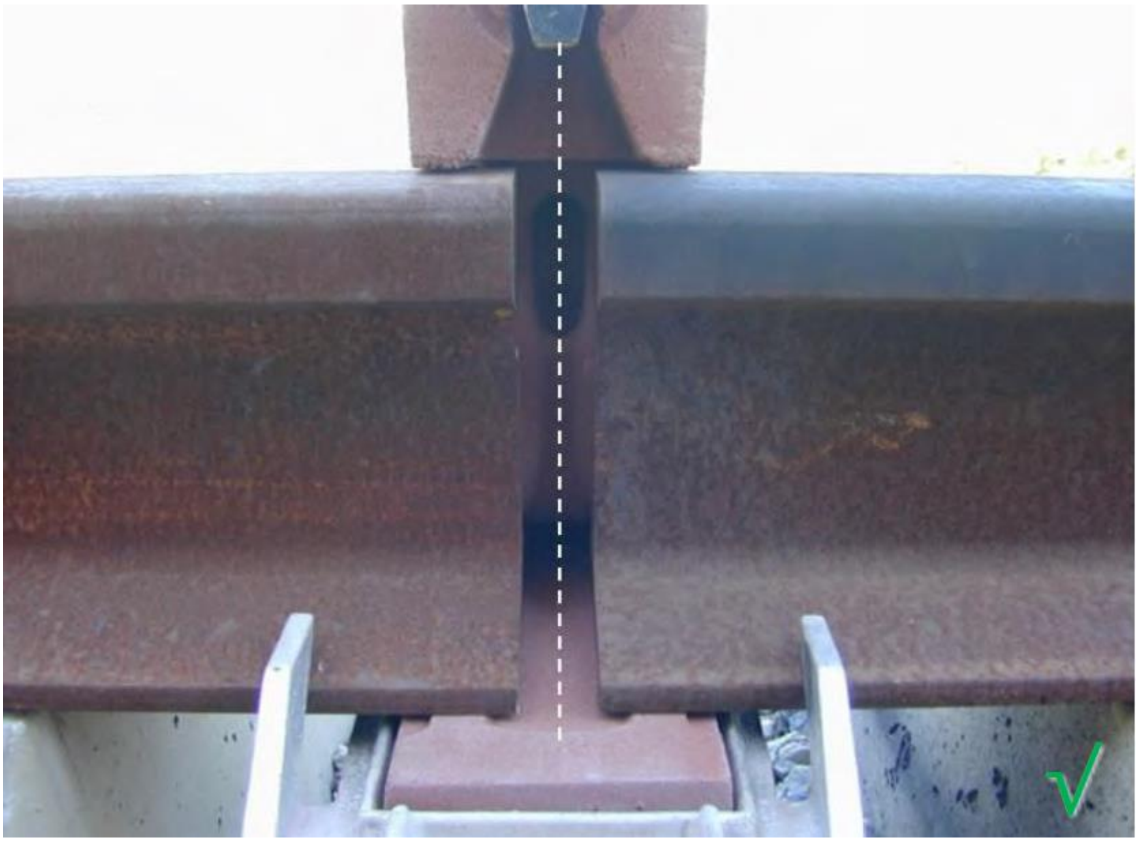


Figure 3: Rail ends prepared vertically and horizontally square

2.4 Rail Weld Gap

- Measure required weld gap, i.e. what is specified in the relevant Supplier manuals for the welding process and rail size in use.
- When the required welding gap has been set, ensure to put in place rail fasteners either side of the weld gap to prohibit movement of the rail, movement will increase or decrease the weld gap width dependant on the Stress Free Temperature (SFT) of the rail. Rail fasteners should not be placed on the closest sleepers to the weld gap, to allow the rail to be set-up and peaked before installing the weld moulds.
- Scribe marks on the parent rail where the rail fasteners closest to the weld gap were placed help to see if the rail has moved. Right before the rail weld moulds are installed, measure the weld gap to ensure it is still of the correct width. Then before pouring of the weld metal occurs, check the scribe marks to see they have not moved.

- When performing a saw cut on a closure rail, the cutting blade should be positioned on the outside of the guide mark for the cut. The opposite should occur when cutting the parent rail, the cutting blade should be positioned on the inside of the guide mark for the cut. The goal is to end with a cut to the rail that is on the centreline of the guide mark for the cut.
- If the rail saw is positioned on the centreline of the guide mark for the cut, the rail saw will cut too much rail. If this occurs, when setting up the weld gap, it may not be possible to achieve the weld gap to tolerance.

2.5 Setup Rail Peak +1.8mm

- When aligning the running surface (top) of the rails to be welded, it is necessary to peak the rails using steel wedges or lifting jacks and an alignment frame. A 1m set up straightedge with 1.8mm nibs at either end is placed centrally over the weld gap. Each end of the straight edge should sit 1.8mm above the running surface, see Figure 4. Peaked welds are preferred over dipped welds as they can be ground to tolerance, where dipped welds are harder to maintain.

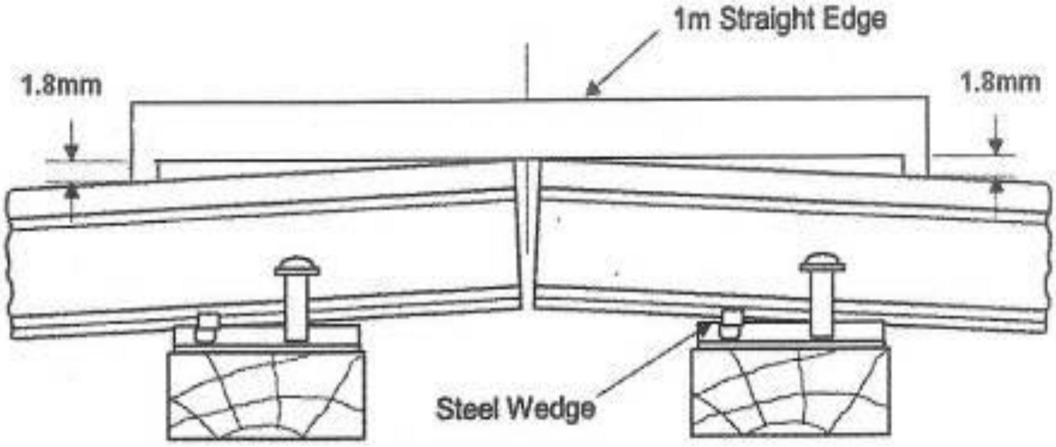


Figure 4: Alignment of running surface - using set up straight edge

2.6 Mould alignment

- Use the correct mould for the rail size and type of weld being performed.
- The mould must be square and central to the rail in all directions.
- When rubbing the mould to achieve a good fit to the rail, take care, don’t be forceful as the mould can break in this region leaving inclusions or increase the risk of runout, which can lead to flashing and/or finning.
- If the rail has not been cut straight, the correct alignment of the weld mould will be difficult to achieve a vertical weld collar (weld collar vertical alignment should be ± 2mm).
- If alignment is incorrect the runner and riser may be partially blocked, causing a bad foot preheat and bad heat transfer from the weld metal, possibly resulting in lack of fusion in the foot.
- When inspecting weld moulds after setting up over the weld gap, the mould should be checked to ensure it is vertically aligned and will obtain evenly distributed heat. To do this the mould risers should be looked through to check that the rail foot is visible and equal on both sides. It is good practice to use a torch to shine into the mould riser to clearly see if both sides of the rail foot are visible and uniform, refer to Figure 5.

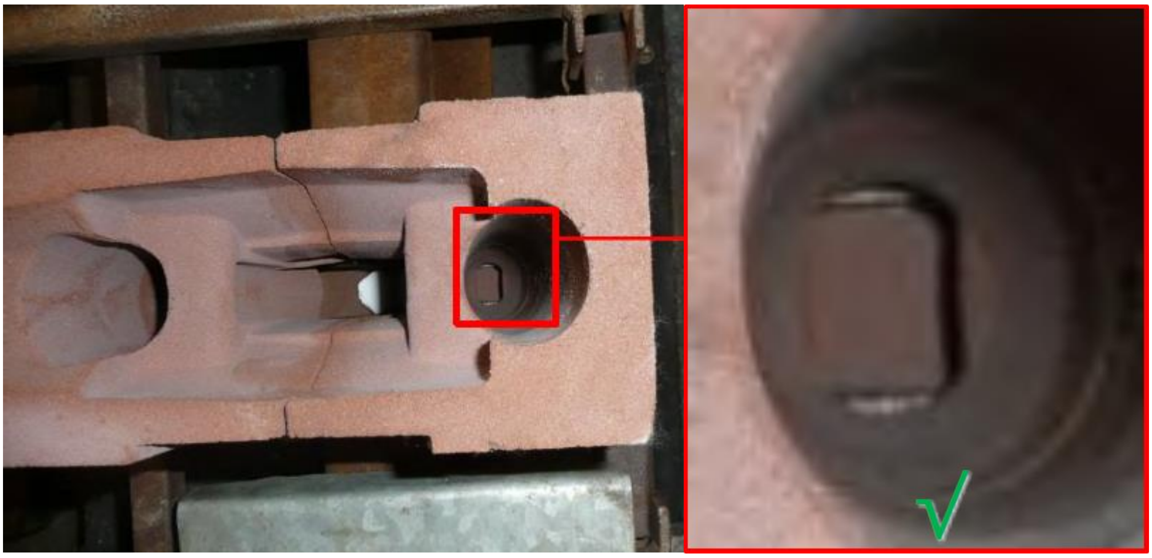


Figure 5: Shine torch through the mould riser to inspect both rail foot sides are uniform

2.7 Sealing of mould to rail "luting"

- Sealing of the moulds to the rail with luting putty should be thorough to prevent weld metal run-out leading to flashing/ finning.
- If there are spaces between the mould and the rail under the foot and head, these gaps can be filled with cardboard to aid with the luting process, refer to Figure 6 and Figure 7 below.

Figure 6: Cardboard filled between weld mould and rail gap (under head)

Figure 7: Cardboard filled between weld mould and rail gap (under foot)

- If there is a gap present between the head of rail and weld moulds, it will be necessary to fit felt, see Figure 8 below.

Figure 8: Fit felt between rail head and weld mould if there is a sufficient gap

- Luting cards can be fitted to cover the head of the rail between the sand moulds and cover the side riser holes, this placement of the luting cards prevents luting putty from falling into the weld gap, which can result in inclusions and porosity in the foot area of the weld.
- Care must be taken to not leave excess luting putty on the top of rail near weld gap, as when shearing takes place this could initiate sand burns.

2.8 Preheat torch type and gas working pressure

- The preheat torch type and gas working pressure (oxygen and LPG/ propane) of the torch should be correct to what is specified in the Supplier manuals for the welding process and rail size in use.

2.9 Torch height and alignment

- Ensure the torch height is correct, set to a neutral flame and preheated for the correct length of time as specified in the Supplier manuals for the welding process and rail size in use.
- The preheat torch should be aligned centrally over the weld mould.
- The above preheating criteria is critical to ensure both rail faces are heated correctly.

2.10 Shearing Criteria

- After the mould has been removed at the correct wait time, following Supplier manuals for the welding process and rail size in use, shearing can be performed.

2.11 Grinding Criteria

- After the excess weld metal is cut off, a rough grind should be performed but should not be cut closer than 1mm to the rail head, as on cooling down the weld could sink and finish out of tolerance. The aim is to set the weld high enough so that after the weld has cooled it will be peaked.
- The weld can be left in its semi-finished condition for 14 days provided it meets the geometry tolerances set out in ARTC standards for semi-finished weld geometry.
- When the weld has sufficiently cooled the final grind should be performed, the grinder should be positioned away from the weld to a flat section of the rail and the grinding stone lowered to just touch the rail, raised a fraction and locked in this position. The grinder is then run across the weld and adjacent rail in long continuous sweeps (at the final position of each sweep, no grinding sparks should be present). This operation is difficult during the initial grinding until the section being ground becomes more uniform. The grinding continues until the grinding zone has become smooth and uniform, within the geometry tolerances set out in ARTC standards for finished weld geometry.
- At a minimum the earliest time to perform the final grind is 1 hour after the semi-finished grind, it is recommended to wait longer if possible. If the final grind is performed too soon, when inspected at the time of grind it could be within geometry tolerance, however when inspected in future (NDT Inspection) will drop and could become a dipped weld.

3 Thermit Aluminothermic Welding Process Variables

Table 5 below shows the values of the variables for Thermit aluminothermic welding processes of different rail sizes.

Table 5: Thermit Aluminothermic Welding Process Variables

Welding Process	Rail Size (kg/m)	Gap Size (mm)	Torch Height (mm)	Gas Working Pressure		Preheat Time (mins)	Mould Removal (mins)	Crown Gap (mm)	Torch Type
				Oxygen (kPa)	LPG / Propane (kPa)				
SkV-Elite (Standard Gap Weld)	31	28 – 30	40	300	50	1.5	5	1.5 – 2	3 Rows / 32 holes
	80lb/40 ACR					2			
	41			400	150	2			
	47					2.5			
	50 – 53					3			
	60					3.5			
	68					4			
SkV-L65 (Wide Gap Weld)	31	60 – 70	35	500	150	2	6 – 7	2.5 – 3	3 Rows / 32 hole
	41 – 53						8 – 9		
SoW-L70 (Wide Gap Weld)	50	60 – 70	60	400	150	3	6 – 7	2.5 – 3	3 Rows / 32 holes
	60					3.5			

Notes:

(1) When preheating junction welds, preheat time is based on the larger rail to be welded.

(2) Preheat torch height is measured from the end tip of the torch to the head of the rail.

(3) Best practice when performing wide gap welds is to revisit the weld 2 – 3 months post-pour and check the rail weld geometry meets ARTC Weld Geometry Standards.

4 Pandrol Aluminothermic Welding Process Variables

Table 6 below shows the values of the variables for Pandrol aluminothermic welding processes of different rail sizes.

Table 6: Pandrol Aluminothermic Welding Process Variables

Welding Process	Rail Size (kg/m)	Gap Size (mm)	Torch Height (mm)	Gas Working Pressure		Preheat Time (mins)	Mould Removal Time After Pour (mins)	Shearing Time After Pour (mins)
				Oxygen (kPa)	LPG / Propane (kPa)			
PLK (Standard Gap Weld)	41	23 – 27	Low Setting Support (40mm)	300 – 320	40 – 45	3	5	6
	47					3		
	50					3		
	53					3		
	60					4		
WGW (Wide Gap Weld)	31	65 – 71	High Setting Support (60mm)	300	50	3	8	10
	41					3		
	47					3		
	50					3		
	53					3		
	60					4		
	68					5		

Notes:

(1) When preheating junction welds, preheat time is based on the larger rail to be welded.

(2) Preheat torch height is measured from the end tip of the torch to the head of the rail.

(3) Best practice when performing wide gap welds is to revisit the weld 2 – 3 months post-pour and check the rail weld geometry meets ARTC Weld Geometry Standards.

5 ARTC Weld Geometry Standards

5.1 Semi-finished Rail Weld Tolerances

Table 7: Semi-finished Rail Weld Tolerances

FACTOR	STANDARD FOR SEMI-FINISHED STATE
Vertical Alignment (Peak in running surface)	+0.8 to +1.2mm over 1 metre (about 1mm preferred)
Vertical Alignment (Dip in running surface)	Strictly no dip allowed
Horizontal Alignment (gauge face)	±0.5mm over 1metre
Collar alignment (Vertical)	Vertical ±2mm preferred, absolute maximum ±4mm

5.2 Finished Rail Weld Tolerances

Table 8: Finished Rail Weld Tolerances

FACTOR	LIMITS	METHOD OF TEST	CORRECTIVE ACTION TO ACHIEVE TOLERANCES
Vertical Alignment (Peak in running surface)	+0.0mm to +0.3mm over 1m, absolute max peak 0.5mm	1m reference and height difference measure	Remove or grind
Vertical Alignment (Dip in running surface)	Nil	1m reference and height difference measure	Remove or lift
Longitudinal straightness (gauge face)	±0.5mm over 1m	1m reference and height difference measure	Remove or grind or bend
Vertical deviation in rail running surface (ramp angle)	7 milliradians or ±0.35mm over 50mm	Measured with dipped weld (P1) gauge or electronic straightedge over 1m	Remove or grind
Collar alignment (Vertical)	Vertical ±2mm preferred, absolute maximum ±4mm	A square gauge and steel rule or weld collar alignment gauge	Remove

5.3 Peaked and Dipped Weld Measurements

Required inspection measurements should be taken with a 1 metre straightedge, metric taper gauge, feeler gauge or electronic measuring system.

Peak welds in the rail running surface should be measured using an ARTC Finishing Straightedge (1 metre straightedge with 0.5mm lugs at either end). The centre of the straightedge should rest on top of the welded joint firmly, the lugs should be facing downward toward the rail. For a weld to pass the peak-test both lugs must touch the rail, refer to Figure 9. From Table 8, the tolerance upon completion for a peak weld in the running surface is between 0mm - 0.5mm, however the preferred maximum is 0.3mm.

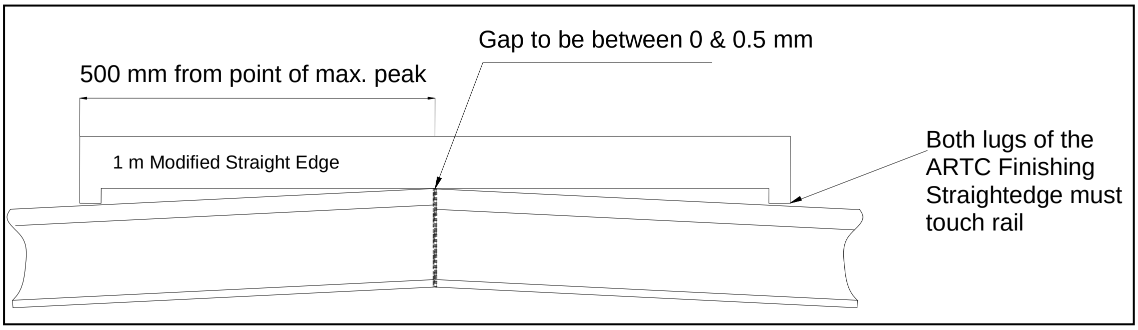


Figure 9: Peak weld measurement using the ARTC Finishing Straightedge

For the measurement of dipped welds, the centre of the ARTC Finishing Straightedge should rest on top of the welded joint firmly, the lugs should be facing upward away from the rail, refer to Figure 10. The taper gauge should try to be inserted under the centre of the straightedge between the welded joint. There should be no daylight between the straightedge and the rail surface. As specified in Table 8, strictly no dip is allowed in the running surface of the rail.

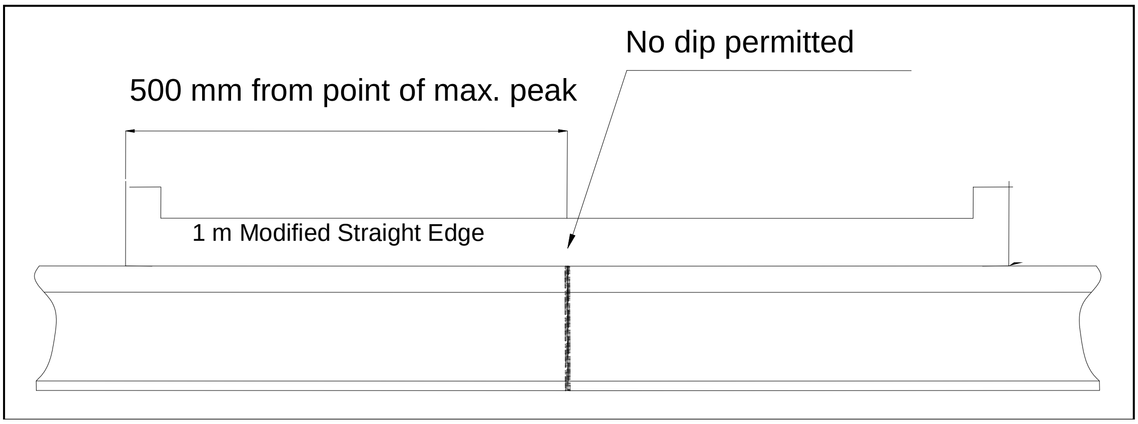


Figure 10: Dipped weld measurement using the ARTC Finishing Straightedge

Note: *In some cases, it may be necessary to extend grinding beyond the extent shown on Figure 9 and Figure 10, when there are nearby variations in rail geometry which are non-compliant with the standards specified in Table 8. The standards specified in Table 8 must be achieved over the entire area in the vicinity of the weld.*

5.4 Vertical Deviation (Ramp Angle) Measurements

The critical factor in the rail surface limits is the ramp angle see Figure 11, measured with a dipped weld gauge (P1 gauge) or an electronic straightedge, over the full extent of grinding of the weld.

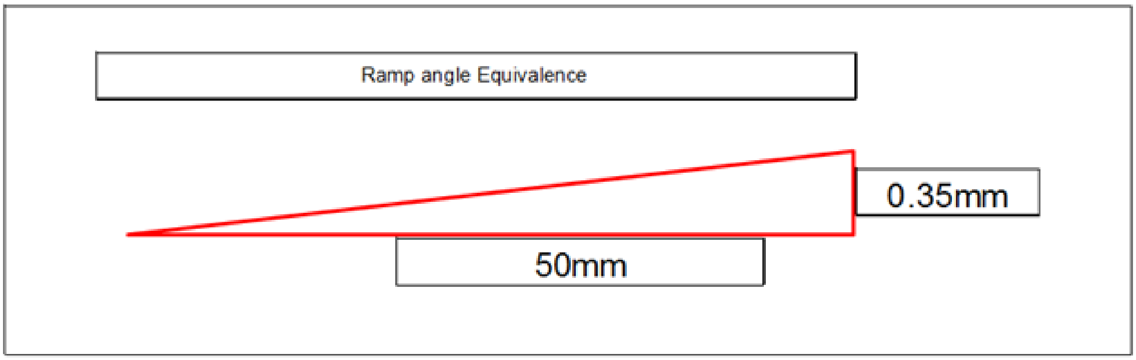


Figure 11: Ramp angle equivalence to 7 milliradians

The P1 gauge in Figure 12 below, is a tool used to verify vertical deviation (ramp angles) in the rail running surface. As specified in Table 8, ramp angles should not be inspected as greater than 7 milliradians or ±0.35mm over 50mm. To measure, the P1 gauge is placed on the rail running surface, the P1 gauge should measure from the start of the grinding zone to the end of the grinding zone, to ensure the ramp angle is within the required tolerances.

Figure 12: P1 gauge ramp angle measurement device

There may be occasions where peak and dip are within tolerance but the change in ramp angle recorded by a P1 gauge may be outside the permitted tolerance. Such a situation is illustrated in Figure 13.

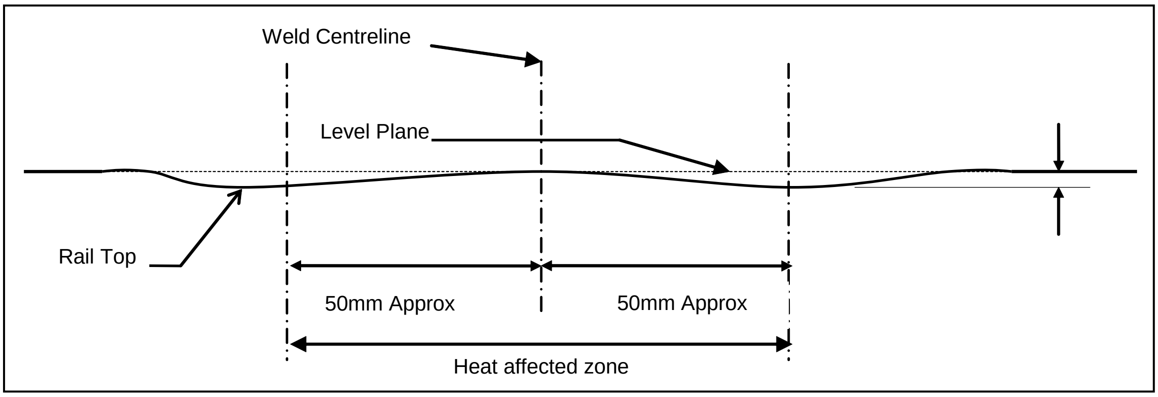


Figure 13: Vertical deviation in rail running surface (weld ramp angle)

Changes in the weld ramp angle over a small base length must be assessed with a P1 Gauge or electronic straightedge, to determine whether the weld finish meets the requirements for ramp angle.

5.5 Electronic Straightedges

Peaked welds, dipped welds and weld ramp angles can all be measured with an electronic straightedge. Electronic straightedge provides a higher level of accuracy and consistent measurements, see Figure 14 and Figure 15. It also creates records that can be used for traceability. Traditional systems were created as a go or no-go setup where welds either pass or fail. The electronic straightedge can provide feedback on the shape and discover areas for improvement where the compliance could be marginal. In addition to this, the mechanical straightedge and P1 ramp angle gauge requires a large amount of user input where this can cause variability in the results.

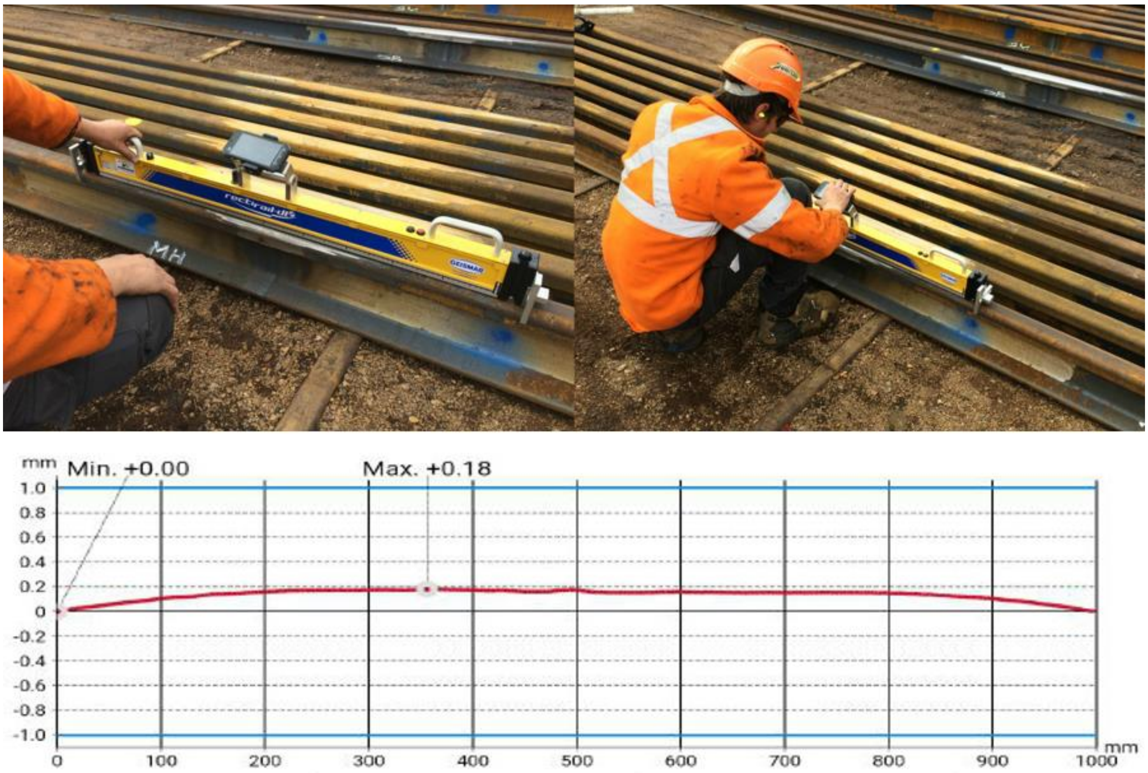


Figure 14: An example of a good weld geometry captured by the electronic straightedge

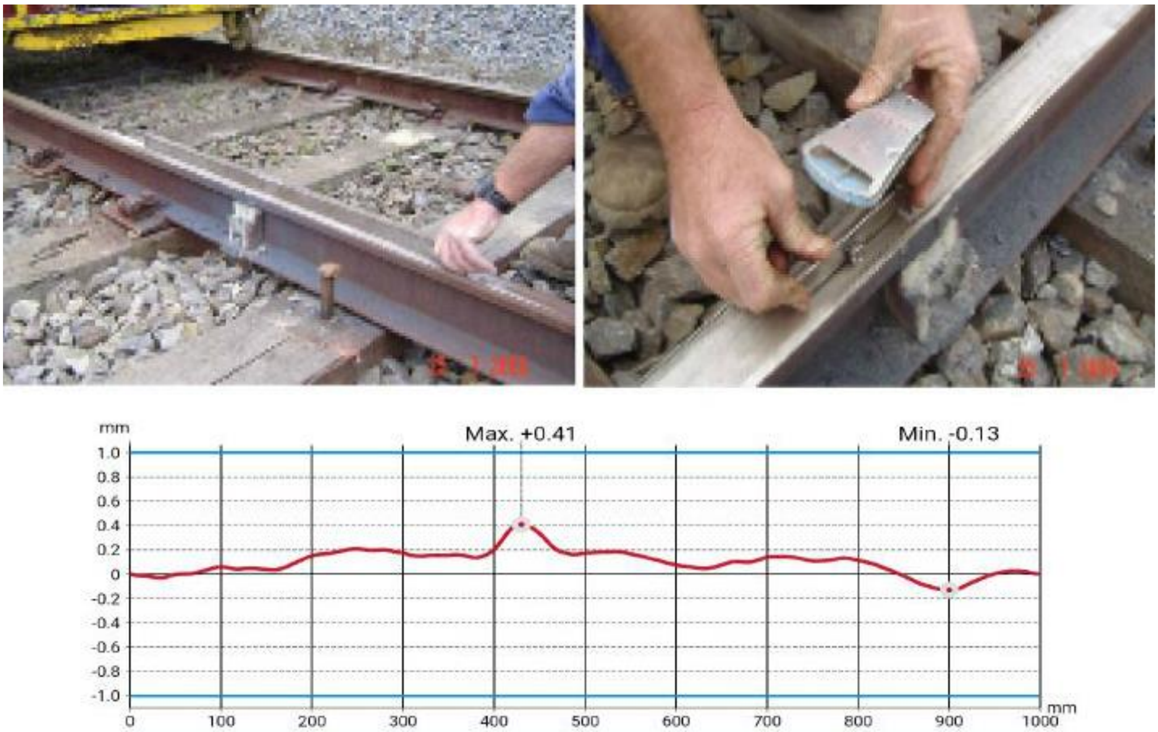


Figure 15: An example of a failed weld geometry measured by an electronic straightedge which was accepted by traditional methods

The inputs for the electronic straightedges are the same as for the 1 metre straightedge however more comprehensive outputs are created with peaks, dips and ramp angle being able to be measured through one device.

Electronic straightedges are the preferred method for checking finished welds.

5.6 Horizontal Alignment measurements

To measure horizontal alignment (gauge tightening) in rail, similar to the peaked weld measurement. The centre of the ARTC Finishing Straightedge should be held firmly on the gauge face of the welded joint, the lugs should be facing toward the gauge face of the rail, see Figure 16. For a weld to pass this test both lugs must touch the rail. From Table 8, the tolerance upon completion for gauge narrowing due to change in rail is 0.5mm.

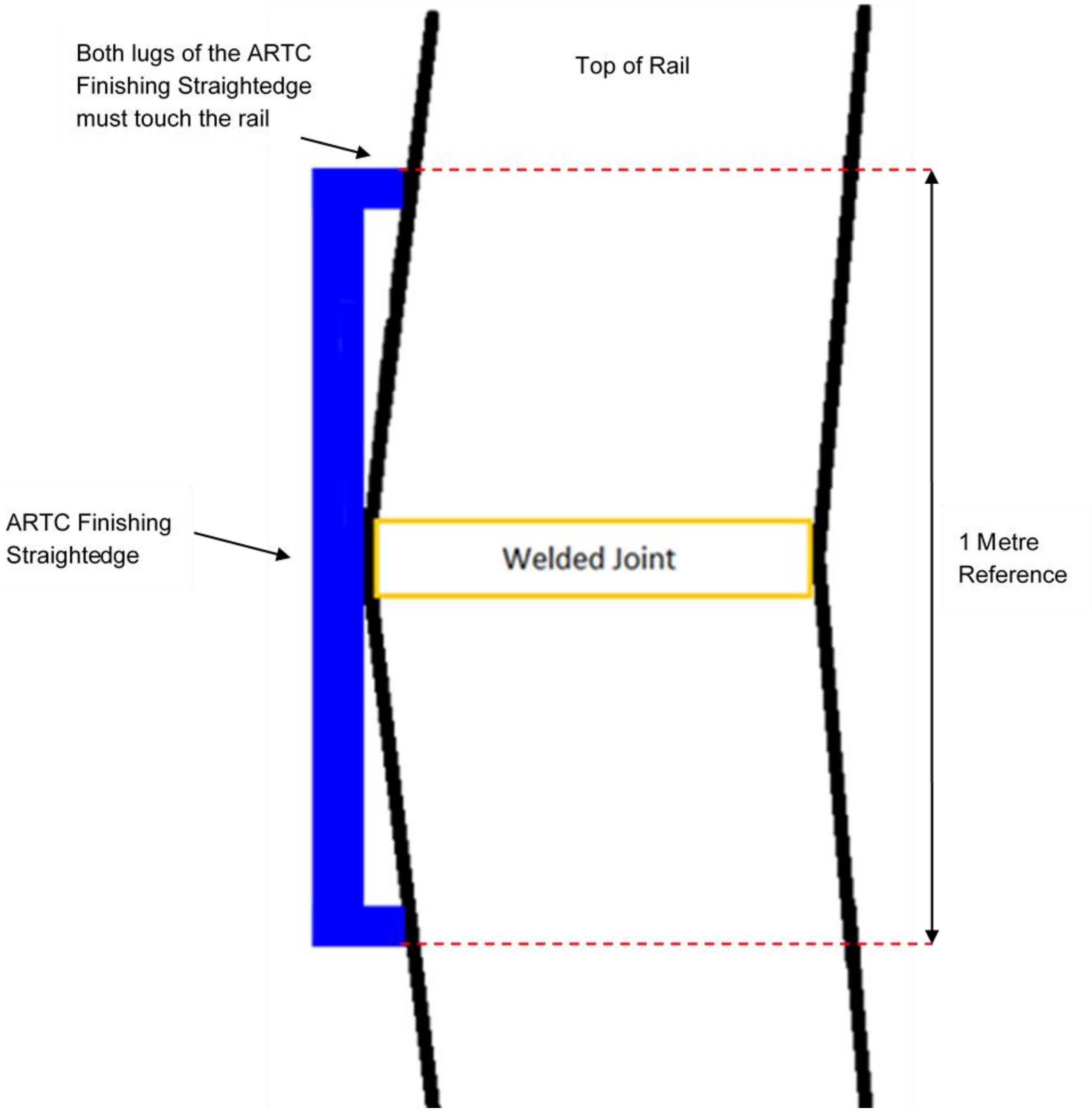


Figure 16: Measurement of gauge narrowing due to change in rail

To measure horizontal alignment (gauge widening), similar to the dipped weld measurement. The centre of the ARTC Finishing Straightedge should be held firmly on the gauge face of the welded joint, the lugs should be facing away from the gauge face of the rail. The taper gauge should try to be inserted between the centre of the straightedge and the welded joint, see Figure 17. From Table 8, the tolerance upon completion for gauge widening due to change in rail is 0.5mm.

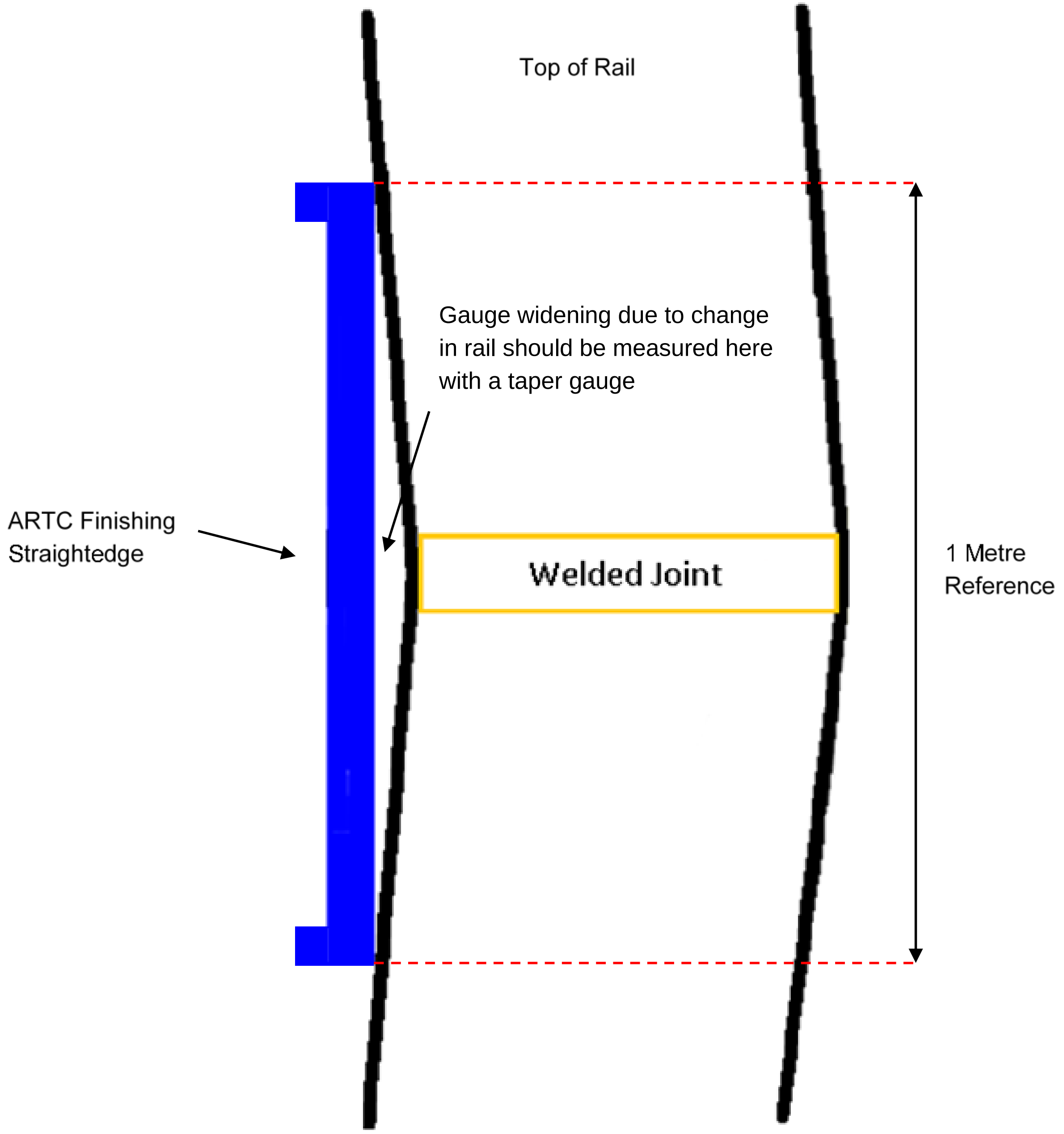


Figure 17: Measurement of gauge widening due to change in rail

To inspect horizontal alignment on curves, the 1m straightedge can be used as a guide, however a visual inspection must be performed to ensure the transition of the curve remains acceptable and the welded rail is not twisting.

5.7 Vertical Step in Rail Running Surface Measurements

A vertical step in the rail running surface can occur if the top surface of the rails to be welded are not aligned properly (more common in flashbutt welds). If one rail end sits lower than the other after welding see Figure 18, grind a uniform taper surface from the end of the high rail to the end of the low rail see Figure 19. This can be measured with the ARTC Finishing Straightedge or better with the electronic straightedge.

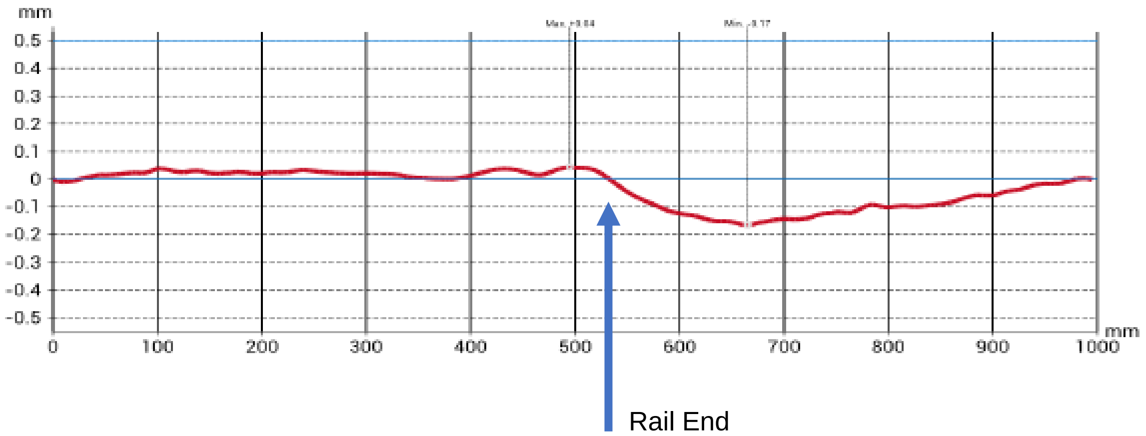


Figure 18: Electronic straightedge (one rail welded higher than the other)

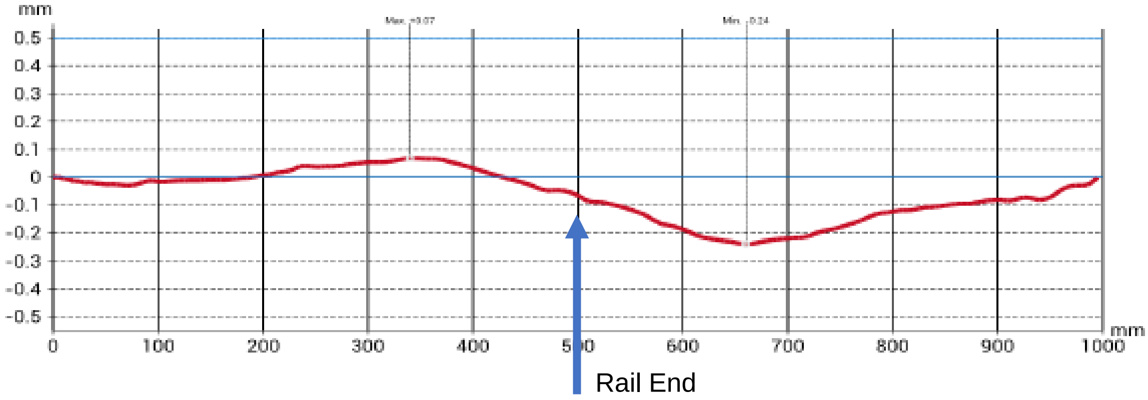


Figure 19: Electronic straightedge (uniform taper surface ground from the end of the high rail to the end of the low rail)

5.8 Vertical Alignment of Weld Collars Measurements

Vertical misalignment of the weld collar is a defect where the weld collar is not situated perpendicular to the rail, due to misaligned moulds. From Table 8, the vertical alignment of the weld collar should be within ±4mm, but it is preferred to be aligned within ±2mm. Misaligned moulds do not allow preheating to occur evenly and it causes poor heat distribution in the weld. Alignment of moulds and a vertical weld collar are critical to ensure complete fusion across the full weld face, particularly at the foot of stepped and junction welds. Poor alignment can lead to lack of fusion, cold laps, and in extreme cases, shrinkage defects.

Due to the rough and irregular nature of weld collars it is usually impossible to take direct measurements at the edges of the weld without some margin of error. However, it is possible to judge and estimate these angles using a ruler as guidance;

- Where the weld collar is visually consistent in thickness from the head to the foot, and good reference points can be seen on the web of the rail-to-collar edge for measurement at the top and bottom of the web; measurements are to be taken as estimates of the weld angle.
- To determine the vertical baseline (at exactly 90 degrees to the rail foot) a square rule of at least 200mm is required.

- When placed on the foot of the rail the square must be exactly parallel to the foot edge, with the bottom edge of the square either underneath or on the top surface the foot.
- The foot surface where the square touches must be clean and free of any bumps or material that may tilt the square incorrectly.
- In order to measure the vertical alignment of the weld; a measurement between the weld collar edge and the square rule should be taken at both the top (head) and bottom (foot) of the rail height. If the square is pushed up against the collar edge, then one of these measurements will obviously be 0 mm, no gap, and the other measurement is taken as the value for misalignment.

Response Actions;

- Misalignment of the weld collar must not be measured as being greater than 4mm misaligned from the head to the foot.
- Welds measured or judged above 4mm misalignment shall be removed from track within the following time frames;
  - Heavy haul lines welds shall be removed within 28 days,
  - Non-heavy haul lines welds shall be removed within 90 days.

Figure 20 shows, how the square rule should be positioned to measure the vertical alignment of the weld collar. At this stage, a steel rule should be used to measure the distance between the square rule and weld collar at the head of the rail.

Figure 20: Poor vertical alignment of the weld collar measured with a square rule

Figure 21 and Figure 22 detail failed welds as a result of poor alignment of weld moulds, leading to misalignment of the weld collars.

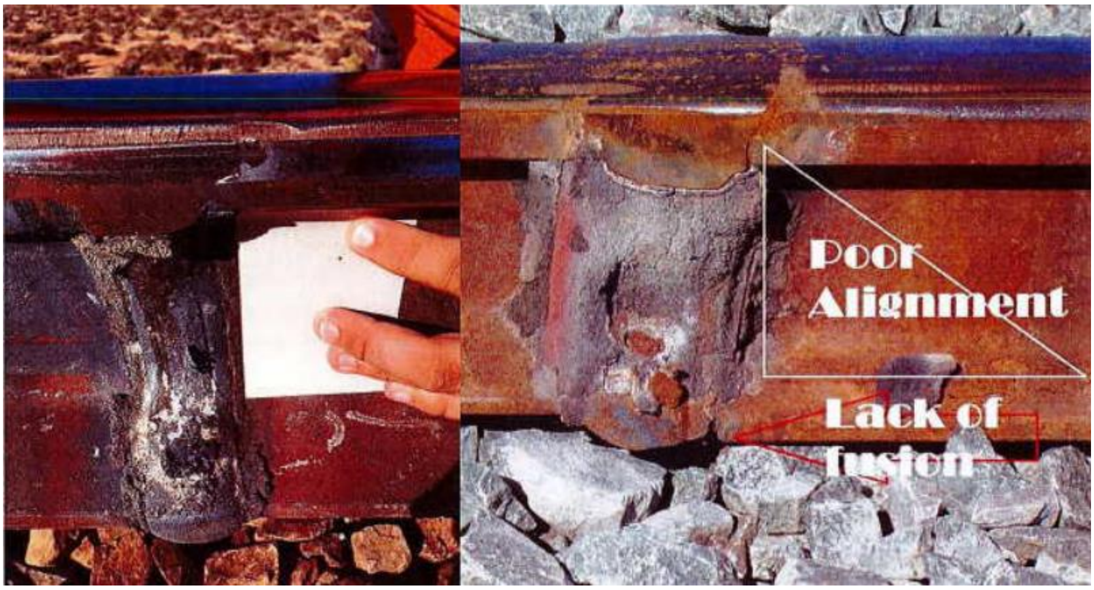


Figure 21: Failed weld due to misalignment of the weld collar

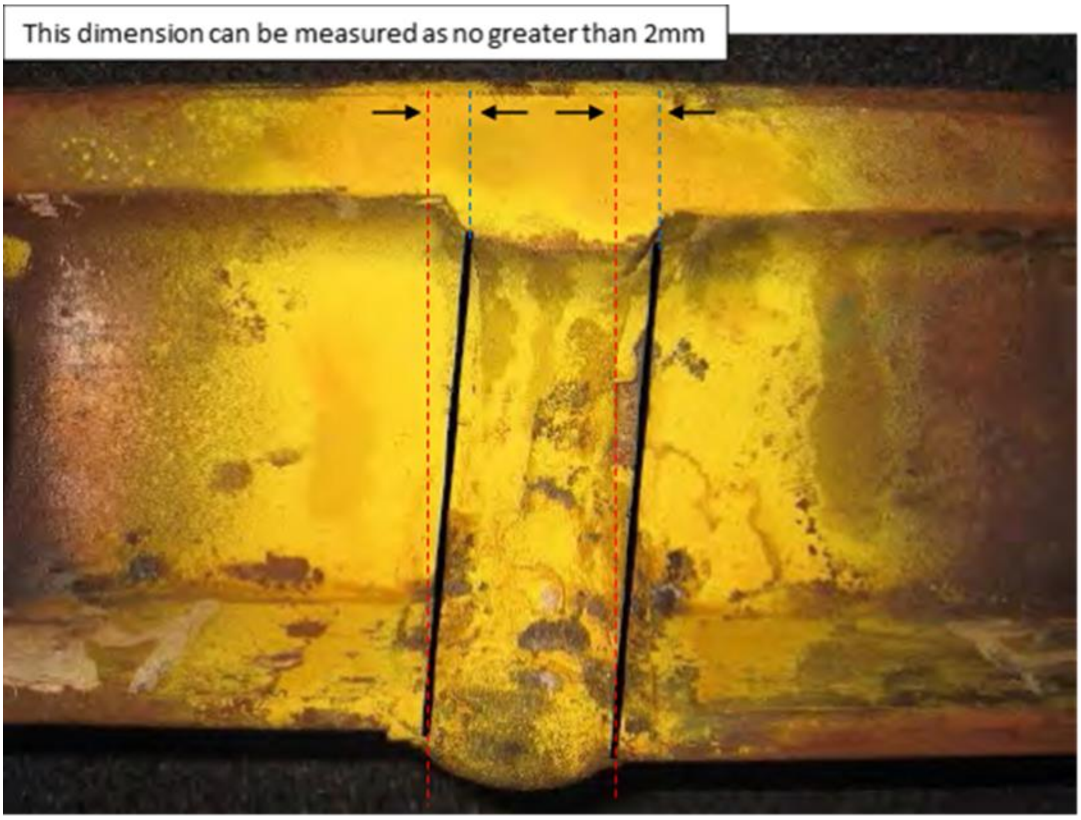


Figure 22: Failed weld due to misalignment of the weld collar 2

6 Visual Inspection of Welds

To facilitate visual inspection of the weld, the welder must thoroughly clean the weld, this occurs after the weld risers have been removed. To perform the clean, ensure all weld mould debris has been removed from the following areas:

- Underside of head,
- Around vent riser position, and
- Underside of collar.

The removal of the mould material can be done with a needle scaler. If a needle scaler is not available use a hammer and cold set (steel chisel) to remove excess mould material, then clean the weld collar with a wire brush to ensure the weld can be properly visually inspected. Figure 23 below illustrates a properly cleaned aluminothermic weld, that can be visually inspected.

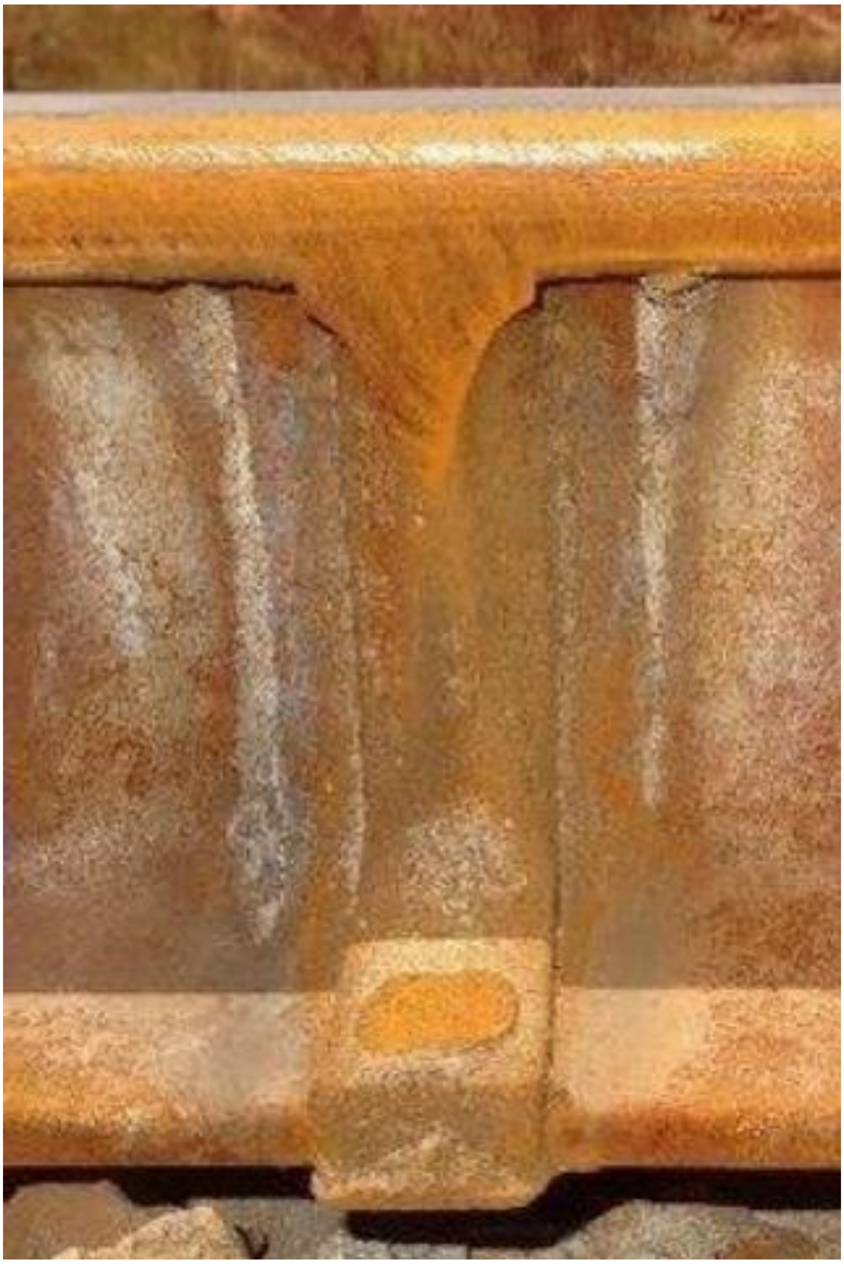


Figure 23: Properly cleaned aluminothermic weld

The underside of the weld collar should be checked for signs of the following: oxidisation, flashing, fit-up of moulds at collar junction (2-piece), weld collar deformation and incomplete collar.

The weld should be visually checked around by the qualified welder after the weld has been completed and prior to leaving the worksite for signs of the following:

- porosity,
- hot tears,
- lack of fusion,
- inclusions,
- vent riser break-off point (black holes),
- sand burns/paste scars,
- cracks,
- flashing/finning,
- vertical misalignment of the weld collar,
- oxidised/glazed welds and incomplete weld collar.

Use a hand mirror to inspect under the rail head (web to head transition), refer to Figure 24.

Figure 24: Mirror to check under side of the rail head

The following sections illustrate and detail rail weld defects, that can be visually inspected post-weld.

6.1 Porosity

What is the Defect.

Spherical voids located within the weld metal, that may be isolated/ grouped, internal and surface breaking. The porosity defect is of major concern as it may be concealed within the rail weld and not noticeable on the outside through visual inspection.

Image of the defect.

Figure 25: Rail Weld Defect (Porosity)

Root cause of the defect.

Porosity is caused by moisture as a result of one or more of the following conditions disturbing the weld reaction:

- Wet luting paste/ sand,
- Damp crucible,
- Damp portions,
- Wet moulds,
- Rain present in the location of the weld,
- Failure to keep the weld dry, and
- Self-tapping thimble releasing too early.

Moisture present in the reaction can create voids (porosity) within the weld. These voids can be found anywhere in the weld; head, web and foot.

What can be changed to prevent the defect occurring in future welds.

Moisture can come from; the crucible, the moulds (majority of the time) and the portion. To avoid this occurring:

- Store the aluminothermic welding consumables in a sealed, dry location.
- Preheating should be performed per supplier’s manual in order to remove moisture from the moulds and from the rail.
- The crucible should be preheated before use to remove any moisture, a preheat time of 20 minutes for the multiple-use crucible and 30 minutes for the one-shot crucible.
- Do not prepare the portion too early in the crucible where it can contact water.
- Don’t weld in the rain, unless it is an emergency. Then a fire-resistant tent must be used.

Action steps.

Refer to Section 1 Rail for guidance on the remedial action to take for rail weld defects.

6.2 Hot Tear

What is the Defect.
Weld tears due to incorrect shearing of the weld, will display a surface breaking tear across the gauge and/or field side of the rail head, see images below.

Image of the defect.

Figure 26: Rail Weld Defect (Surface breaking hot tear in weld)

Root cause of the defect.

Hot tears occur from movement of the rail weld before the steel has solidified sufficiently. This movement can occur from;

- Incorrect shearing (time / temperature / equipment),

What can be changed to prevent the defect occurring in future welds.

The weld should be allowed to cool sufficiently before removing the mould and shearing. This wait time before shearing is specified in the user manuals for the each of the welding process and rail size in use.

When using manual weld shears, it is found easier to trim the weld when it is hot, therefore it is appealing to shear the weld earlier than should be done. The weld should not be sheared earlier then specified, if welds are hard to shear, automatic weld shears should be used to make operation easier to trim the weld when it has cooled sufficiently.

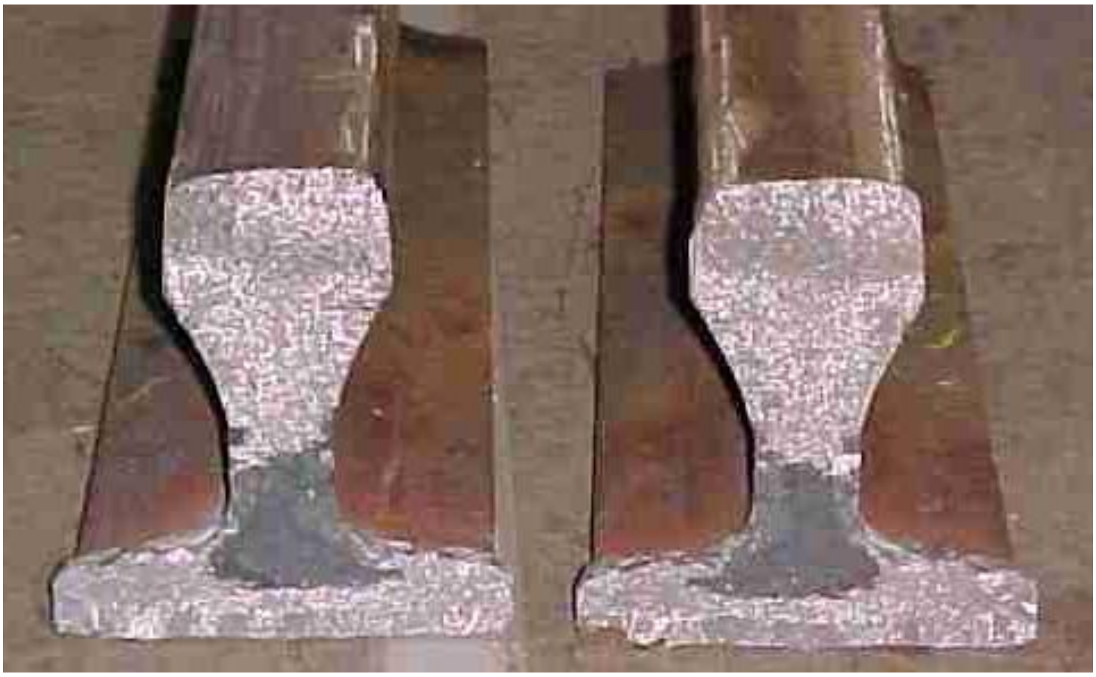
Action steps.

Refer to Section 1 Rail for guidance on the remedial action to take for rail weld defects.

6.3 Rail Weld Shrinkage Defect

What is the Defect.
Shrinkage defects occur due to movement of the rail weld before the steel has solidified sufficiently. Known as a transverse vertical defect in the rail foot and/or lower web area.

Image of the defect.



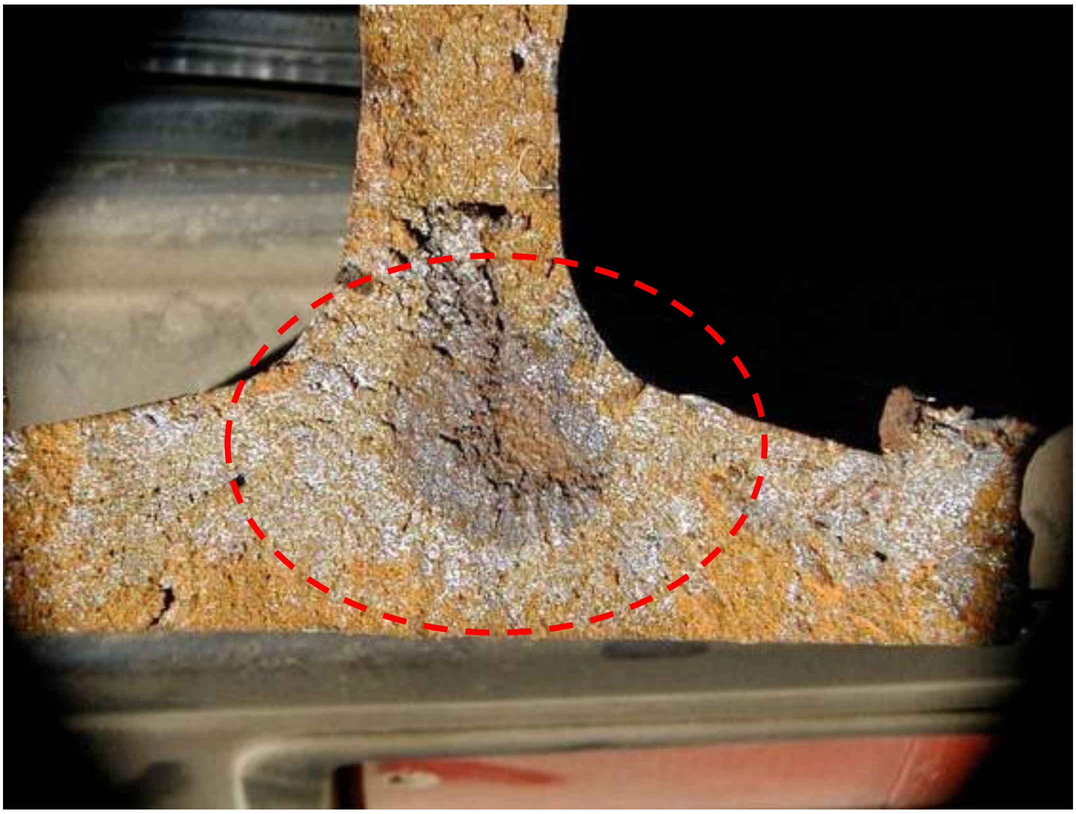


Figure 27: Rail Weld Defect (A transverse vertical hot tear defect in rail foot and/or lower web area)

Root cause of the defect.

- Any rail movement or vibration during the solidifying time,
- Insufficient preheat prior to welding,
- Trains passing on adjacent track,
- Rail bound vehicles passing over weld too early,
- Movement of jacks or alignment support devices,
- Tensor slip and
- Rising or falling temperature.

What can be changed to prevent the defect occurring in future welds.

Do not allow any rail movement or vibration during the solidifying time.

Do not allow rail bound vehicles to pass over the weld before it has sufficiently cured.

The weld should be allowed to cool down to below 350ºC to allow it to develop enough strength before any loads are applied. Hot tensile tests have shown that approximately 80 % of the strength is developed at 350ºC. Thermocouple measurements have shown that for welds to cool down to below 350ºC takes approximately 24 minutes.

Inspect rail weld equipment (i.e. jacks, alignment support devices and tensors) to ensure they are in correct working operation.

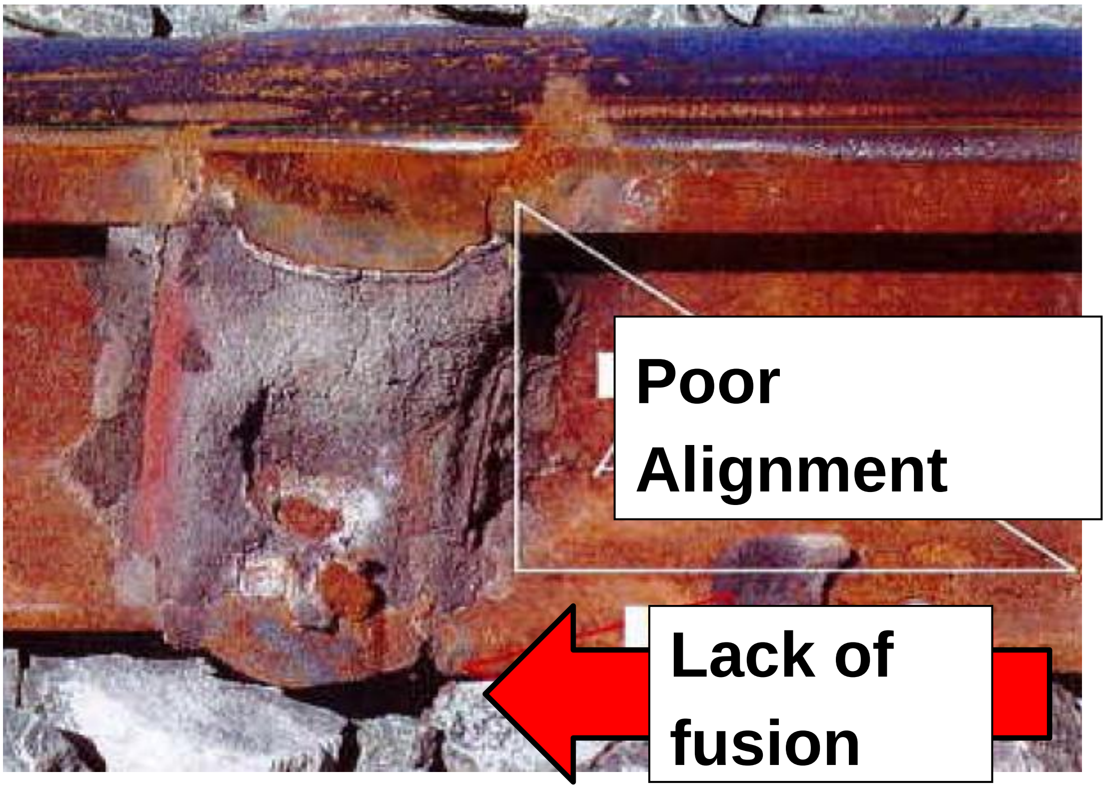
Action steps.

Refer to Section 1 Rail for guidance on the remedial action to take for rail weld defects.

6.4 Lack of Fusion

What is the defect.
Weld metal has not fused with rail, 'usually' occurring in the rail foot and/or head.

Image of the defect.



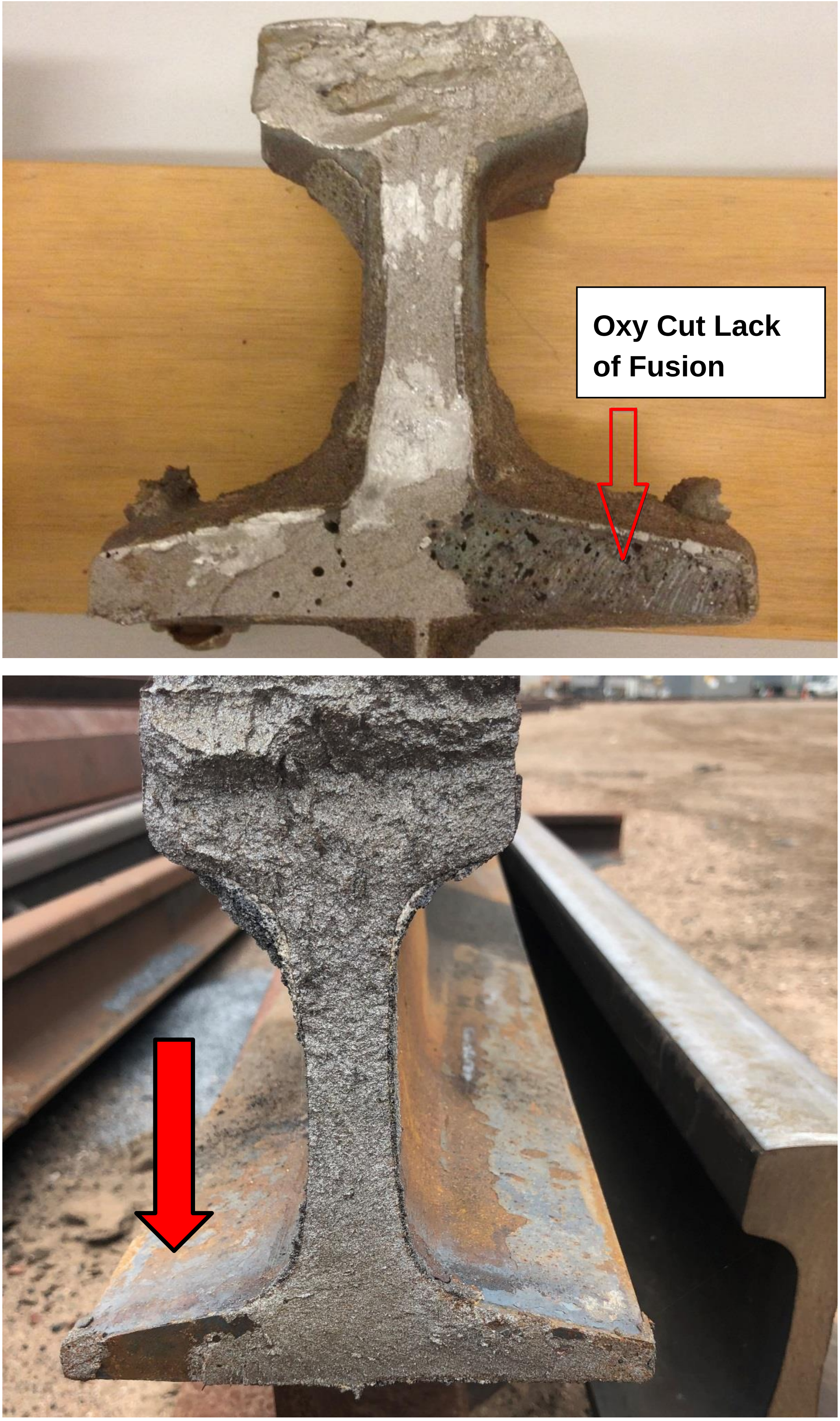


Figure 28: Rail Weld Defect (Lack of Fusion)

Root cause of the defect.

Lack of fusion of a rail weld is caused from impurity of preheating the rail ends before igniting the portion. The rails ends should be uniformly preheated for the time specified in the relevant supplier manuals.

For a long preheat weld process, the preheating torch should uniformly with a neutral flame wash (preheat) both rail ends to a temperature of around 950 to 1000ºC and both rail ends should display a strong bright orange appearance upon completion of the preheating process.

What can be changed to prevent the defect occurring in future welds.

- The cut of both rail faces for the weld gap should be vertical within ± 2mm,
- The weld mould should be vertically and horizontally aligned over the weld gap, if the rail is not cut vertical, correct alignment of the weld mould is difficult (refer to supplier manuals),
- Saw cut the weld, even if the initial cut is flame cut, and
- Ensure all steps are followed to correctly preheat both rail faces uniformly, i.e. setting the preheater torch to the correct height and position over the weld gap, using the correct gas-working pressures, a neutral flame and correct preheat time.
- The moulds should be inspected for any foreign matter that will affect heating during preheating.

Action steps.

Refer to Section 1 Rail for guidance on the remedial action to take for rail weld defects.

6.5 Weld Inclusions

What is the Defect.

Rail weld inclusions are particles of impurity, e.g. mould material, luting material or aluminium oxide (slag), located within the weld metal. If inclusions form in the weld, they will cause weak spots as their metallurgy make-up is not adequate in strength to negotiate the heavy axle loads required.

Image of the defect.

Figure 29: Rail Weld Defect (Weld Inclusions)

Root cause of the defect.

- Failure to place luting cards to prevent luting paste from falling into the weld gap during luting operations, this can result in inclusions in the rail foot.
- In the web area inclusions can occur from excessively rubbing the weld collar recess of the weld mould, when fitting the weld mould to the rail profile.
- Setting a wider weld gap from what was specified in the Supplier manuals for the weld process in use and size of the rail to be welded.
- Lack of preheating to wash both rail faces uniformly.
- Not cleaning or inadequate cleaning of the crucible where multi-use crucibles are used.
- Flame cut surfaces can cause inclusions in the weld zone.

What can be changed to prevent the defect occurring in future welds.

Ensure the aluminothermic weld method defect causes above are done in accordance with the supplier manuals for the weld process and rail size in use, care must be taken when performing each step.

Action steps.

Refer to Section 1 Rail for guidance on the remedial action to take for rail weld defects.

6.6 Blackholes

What is the Defect.

The blackhole weld defect is a wormhole type feature (gas pore) visible after removal of the vent riser. The blackhole defect is typically 2-5mm in diameter, it may penetrate through the riser and into the weld metal, however in most cases the isolated hole is shallow and rounded.

Image of the defect.

Figure 30: Rail Weld Defect (Blackhole in the weld riser)

Root cause of the defect.

The blackhole defect is caused by gas passing through the weld during solidification, leaving a gas pore visible after removal of the riser.

What can be changed to prevent the defect occurring in future welds.

To minimise the occurrence of blackhole weld defects:

- Use the correct weld gap as specified in the Supplier manuals for the weld process and rail size in use.
- Both sides of the rail should be clipped in place after the weld gap has been set, to ensure movement of the rail does not occur before pouring.
- Ensure all weld equipment, weld materials and rail are free from moisture.
- Ensure the preheating of the rail is performed correctly.

Action steps.

Refer to Section 1 Rail for guidance on the remedial action to take for rail weld defects.

6.7 Sand Burns or Paste Scars

What is the Defect.

Sand burns or paste scars are dark marks and/or indentations transverse to the rail which are co-incident to the edges of the weld collar.

Image of the defect.

Figure 31: Rail Weld Defect (Sand Burns)

Root cause of the defect.

Sand burns can occur from:

- Molten or vitrifying luting paste/ sand contacting the rail
- Failure to clean weld around rail head area prior to shearing
- Incorrect weld mould fitting
- Incorrect/poor luting technique
- Weld shearing problems

What can be changed to prevent the defect occurring in future welds.

Ensure the above causes of sand burns that occur through poor method execution are performed to the specification of the Supplier manuals.

6.8 Cracks

What is the Defect.

Rail weld crack defects can occur in the weld and/or in the rail surface where the weld cut is made. The effects of rail weld crack defects:

- Produce incorrect microstructure in the weld
- Change microstructure of parent rail
- Cause elevated hardness
- Induce defects already present in rail to grow into weld

Image of the defect.

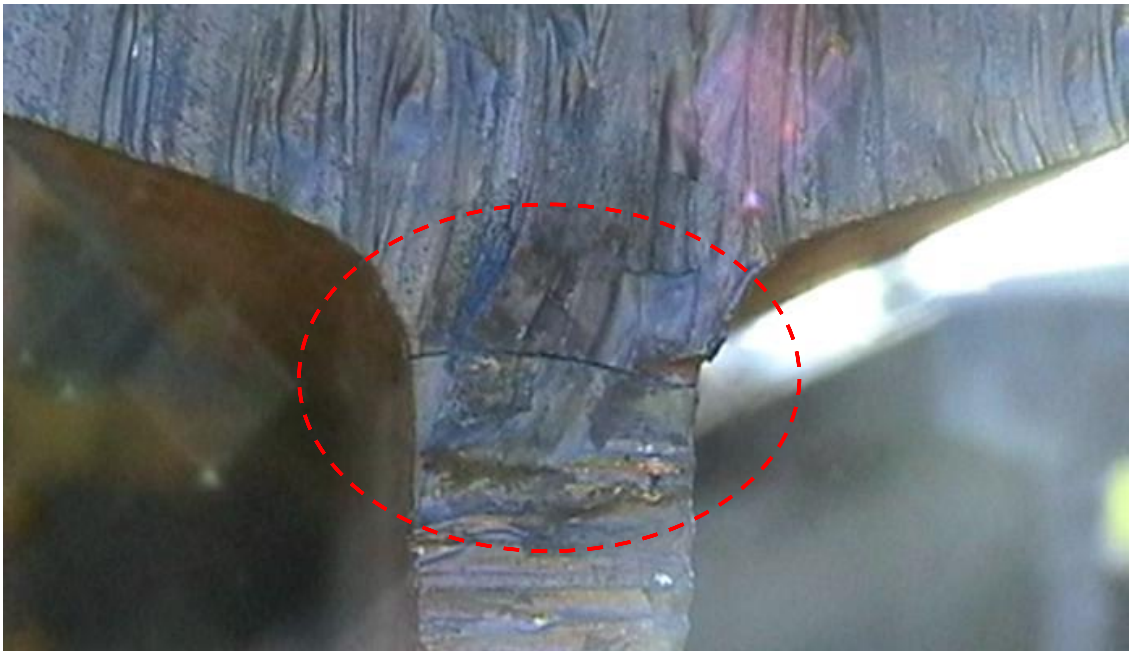


Figure 32: Rail Weld Defects (Cracking)

Root cause of the defect.

Rail weld cracking can be caused by:

- Incorrect portion selection for grade of rail steel being welded
- Flame cutting of rails where the steel grade is not permitted to be flame cut
- Leaving a flame cut rail end in track for too long prior to welding (A flame cut rail end which has been left more than; 12 hours for standard carbon rail, or 4 hours for Head Hardened rail, must be re-cut prior to welding, removing a minimum of 25mm)
- Failure to control/retard the cooling rate of welded rails
- Parent rail problems:
  - Rolling Contact Fatigue (RCF)
  - Star cracks or local fatigue spot
  - Bond problems

What can be changed to prevent the defect occurring in future welds.

- Selection of the correct portion powder for the grade of steel being welded, using the Supplier manuals for reference.

- Do NOT flame cut rails where the steel grade is not permitted to be flame cut, or
    - It is advised for aluminothermic welds that the initial rail cut can be flame cut initially, but the final rail surfaces to be welded should be saw cut. This will help to decrease other rail weld defects, i.e. Lack of fusion in the rail foot due to flame cut rail ends.

- A flame cut rail end which has been left in track more than 12 hours for standard carbon rail, or 4 hours for Head Hardened rail, must be re-cut prior to welding, removing a minimum of 25mm. This is to remove any cracks that may have grown from the original cut, and which could be too long to have been safely melted into the weld metal.

Action steps.

Refer to Section 1 Rail for guidance on the remedial action to take for rail weld defects.

6.9 Flashing or Finning

What is the Defect.

Flashing or finning is caused by molten metal leaking from the weld mould and not fusing with the rail surface, resulting in a mechanical notch that acts as a stress riser. With repeated tensile forces due to train operations, aluminothermic welds can fail where this defect is located.

Image of the defect.

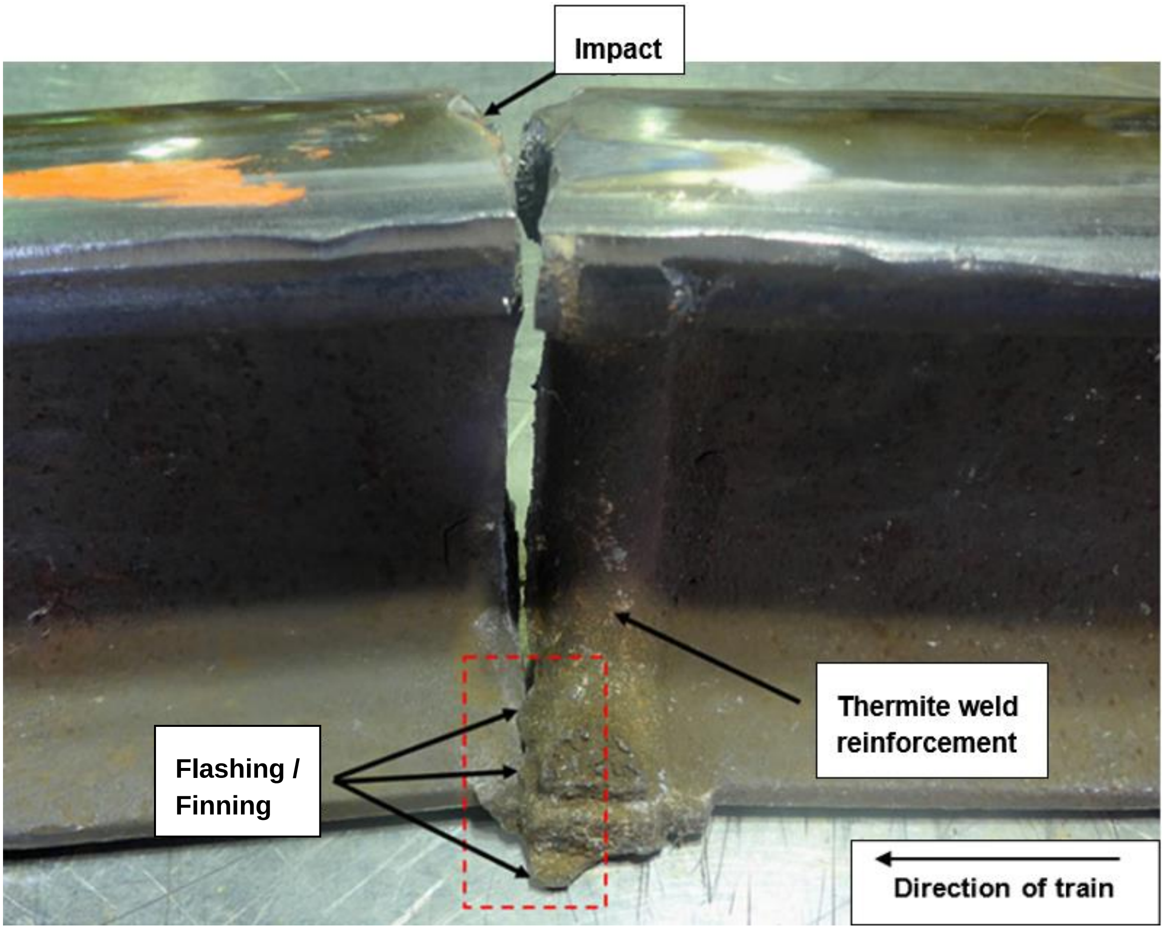


Figure 33: Flashing/finning of the rail weld due to a gap between weld mould and rail (should be ground off post-weld)

Figure 34: Flashing/finning of the rail weld due to broken weld mould (should be ground off post-weld)

Root cause of the defect.

Flashing or Finning occurs from a lack of fitness between the rail weld mould and the rail end surface either from broken weld moulds, or welds where the rail and weld mould have a gap between them (welding rails with dissimilar profiles). Molten metal flows out of the resulting gap between the mould and rail, forming an unfused flash or fin. If inspected post-weld the flash or fin must be ground off. Where these defects exist on heavy haul tracks their removal by grinding is critical as they can cause high stress notches, leading to rapid failure of the weld.

What can be changed to prevent the defect occurring in future welds.

- Weld moulds should be inspected prior to installation for cracks and damage.
- Weld moulds should fit firmly against the rail with the use of a rail clamp to tighten but should not be over tightened as they can break.
- Weld moulds should be rubbed up against the rail, any gaps between the mould and rail after this step should be sealed with luting paste.
- If flashing or finning defect is inspected post-weld it should be ground off, as this will mitigate the weld failing from this defect type.

Action steps.

Refer to Section 1 Rail for guidance on the remedial action to take for rail weld defects.

6.10 Vertical Misalignment of the Weld Collar

What is the Defect.

Vertical misalignment of the weld collar is a defect where the weld collar is not positioned perpendicular to the rail within a tolerance of ± 2mm. This defect is critical to ensure good fusion across the weld face, particularly at the foot of stepped and junction welds.

Image of the defect.

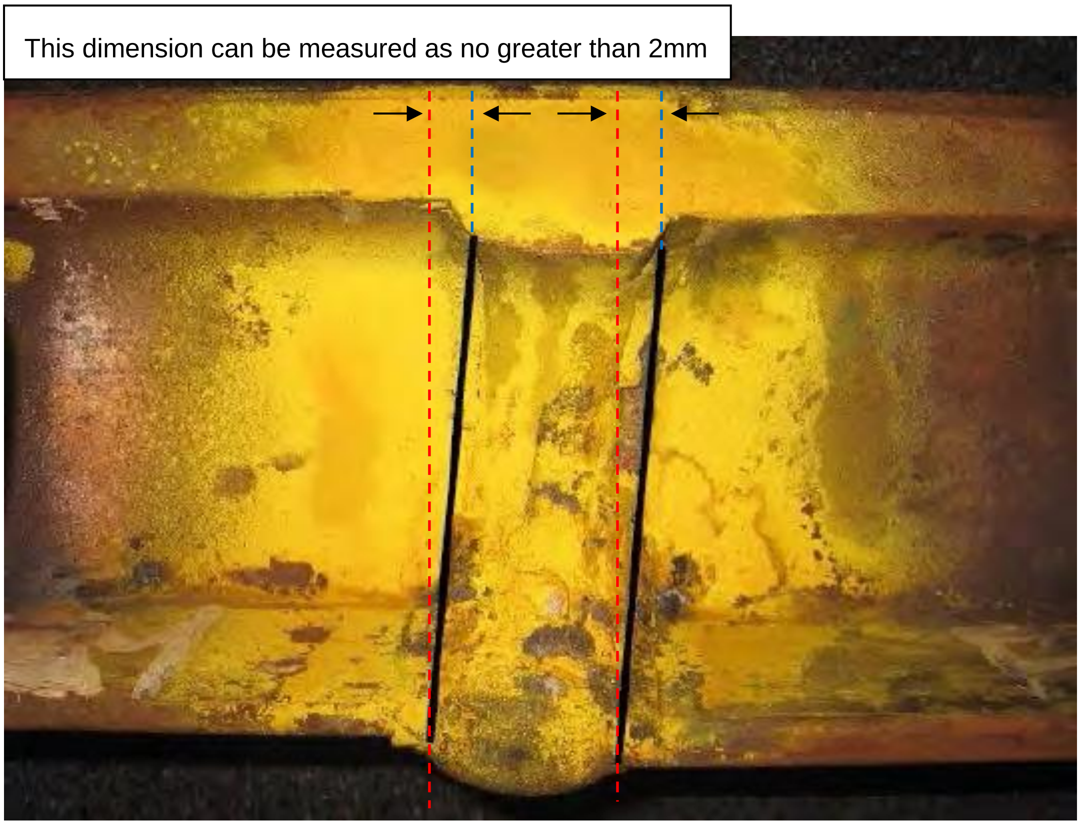


Figure 35: Rail Weld Defect (Weld Collar Vertical Misalignment)

Root cause of the defect.

- Rail not being cut straight, therefore the weld mould is not able to be set-up vertically aligned over the weld gap.
- Poor set-up of the weld mould, even though rail is cut vertical.

What can be changed to prevent the defect occurring in future welds.

- Ensure rail is cut straight, it is preferred to use a rail saw not an oxy cut, even if the initial cut was flame cut.
- Ensure weld mould is set-up vertically aligned over the weld gap.

Action steps.

Refer to Section 1 Rail for guidance on the remedial action to take for rail weld defects.

6.11 Incorrect Preheat (Oxidised/Glazed Welds)

What is the Defect.
Oxidised / glazed welds occur from excessive preheating of the rail faces to be welded. When the weld has been poured and cleaned, the weld collar may show an oxidised / glazed appearance suggesting excessive preheating has occurred.

Image of the defect.

The above image of an oxidised / glazed weld does not clearly depict the defect and when an improved image is taken the above will be replaced.

Root cause of the defect.
This defect is caused by;

- Incorrect preheating flame (gas flow/pressure and burner position),
- Incorrect preheat timing (too long),
- Incorrect gap.

What can be changed to prevent the defect occurring in future welds.
Ensure all steps are followed to correctly preheat both rail faces uniformly, i.e. setting the preheater torch to the correct height and position over the weld gap, using the correct gas-working pressures, a neutral flame and correct preheat time.

Set the correct weld gap for the welding process and rail size to be welded, then install fasteners either side of the weld gap and scribe the rail where the fasteners were placed. Measure the weld gap prior to installing the moulds and before pouring of the weld metal occurs check the scribe marks to see that they have not moved.

6.12 Lack of Collar Formation

What is the Defect.
Lack of collar formation exists when the rail weld collar does not form / join with the parent rail in some locations. This relates to;

- Loss of weld reinforcement,
- Non-symmetrical shape to weld collar, and
- Notch effects created in weld shape.

Image of the defect.

The image above is a cut from a weld, depicting the weld collar under the rail foot. It is trying to illustrate (locations of image with red dashed circles) the section of weld collar that has not fused with the parent rail. The image does not illustrate the defect type very well and when an improved image is taken the above will be replaced.

Root cause of the defect.

This defect type is caused by;

- Damaged moulds,
- Foreign matter within moulds during pouring,
- Incorrect mould fitting,
- Incorrect luting, and
- Moulds over adjusted i.e. collar rubbed away.

What can be changed to prevent the defect occurring in future welds.

- Inspect the weld moulds prior to installation for any damage or cracks,
- Prior to pouring of the weld metal, inspect the weld moulds for any foreign matter i.e. luting material, broken off mould, etc.,
- Care should be taken when rubbing and luting of the weld mould to fit the rail, and
- When tightening the weld mould, ensure not to overtighten the mould as it may break.

Action steps.

Refer to Section 1 Rail for guidance on the remedial action to take for rail weld defects.

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