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BSI Standards Publication

Railway applications — Track — Aluminothermic welding of rails

Part 1: Approval of welding processes

National foreword

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European foreword

This document (EN 14730-1:2017) has been prepared by Technical Committee CEN/TC 256 “Railway applications”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2017, and conflicting national standards shall be withdrawn at the latest by September 2017.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 14730-1:2006+A1:2010.

The European Standard EN 14730 “Railway applications – Track – Aluminothermic welding of rails” is composed of two parts:

- *Part 1: Approval of welding processes*
- *Part 2: Qualification of aluminothermic welders, approval of contractors and acceptance of welds*

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

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Introduction

This standard defines the approval procedure for aluminothermic welding processes for rail welding through laboratory tests of welds produced in a workshop. This laboratory approval will provide the railway authority with sufficient information for tests in the track if required.

1 Scope

This European Standard defines the laboratory tests and requirements for approval of an aluminothermic welding process using welds produced in workshop conditions.

It applies to the joining of new Vignole rails as described in EN 13674-1 of the same profile and steel grade.

Compliance with the requirements of this standard does not of itself ensure the suitability of a welding process for specific conditions of track and traffic.

The standard does not cover welds made between different rail sections, differently worn rails and different rail grades.

In addition to the definitive requirements this standard also requires the items detailed in Clause 4 to be documented. For compliance with this standard, it is important that both the definitive requirements and the documented items be satisfied.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 13674-1, *Railway applications - Track - Rail - Part 1: Vignole railway rails 46 kg/m and above*

EN ISO 6506-1, *Metallic materials - Brinell hardness test - Part 1: Test method (ISO 6506-1:2014)*

EN ISO 6507-1, *Metallic materials - Vickers hardness test - Part 1: Test method (ISO 6507-1:2005)*

EN ISO 9712, *Non-destructive testing - Qualification and certification of NDT personnel (ISO 9712:2012)*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1

fusion zone

area of the weld which has been in a liquid state and which is revealed by etching sections cut through the weld

3.2

visible heat-affected zone

areas on either side of the fusion zone within which rail steel microstructure has been visibly modified by the heat of the welding process as revealed by Fry macro-etching

3.3

heat softened zone

part of the Heat Affected Zone (HAZ) characterised by a lower hardness

3.4

weld collar

external profile of the as-cast weld metal that remains after removal of the moulds

3.5

flashing

flat fin of weld metal located on the rail surface adjacent to the weld collar caused by gaps between the mould and the rail

3.6

surface defect

any defect visible on the weld surface after normal finishing operations

3.7

internal defect

any defect that is revealed by sectioning or on a fracture face following bend or fatigue testing that has not already been identified as a surface defect

3.8

stress range

stress range for the fatigue test is the maximum stress minus minimum stress

3.9

railway authority

either the railway regulator or the owner of a railway infrastructure or the custodian with a delegated responsibility for a railway infrastructure

3.10

process supplier

company which provides an aluminothermic welding process in accordance with this standard and which is approved by the railway authority to supply consumables and tools for the execution of aluminothermic welds

4 Information to be supplied by the railway authority

The following information shall be fully documented by the railway authority. For compliance with the standard both the definitive requirements specified throughout the standard and the following documented items shall be satisfied.

- a) Pre-heating shall comply with any limitations of the railway authority.
- b) Which of the width levels of heat-softened zone is required (7.4.4).
- c) The fatigue test, if required by the railway authority, either past the post or staircase method, shall be carried out in accordance to Annex J and to the requirements as specified in 7.5.

5 Approval procedure

5.1 General

An outline of the steps required for compliance to this standard is given in informative Annex A.

5.2 Process identification

The approval shall involve a single process identified by:

- a) The process name.
- b) A drawing of the pouring system.

- c) The characteristic geometry of the weld collar and riser configuration as given in 5.4.2 and Figure 1.
- d) The process manual in accordance with 5.4.1.

5.3 General requirements

The following requirements shall be met.

- The process shall be capable of being carried out on track where the maximum cant can be 180 mm. It shall be capable of being carried out in track, at or near trackside or in a workshop.
- The aluminothermic welding portion shall be packed to avoid the risk of moisture contamination in prescribed storage conditions. The portion shall be identified by markings on the package.
- The mould shall be pre-fabricated for the rail profiles to be welded and be identified by markings on the package.
- The crucible shall be tapped automatically (automatic tapping) and shall have a device to limit spattering.

5.4 Documents to be submitted with the request for approval

When applying for approval, the following documents shall be submitted:

5.4.1 The process manual

The supplier shall produce a manual identifying all the consumable materials and equipment used, as well as the operating method to be followed for all steps of welding. The approval procedure for laboratory tests shall not include means of alignment or finishing operations. The manual shall specify the critical parameters of the welding process and their safe bounds, and shall include the following:

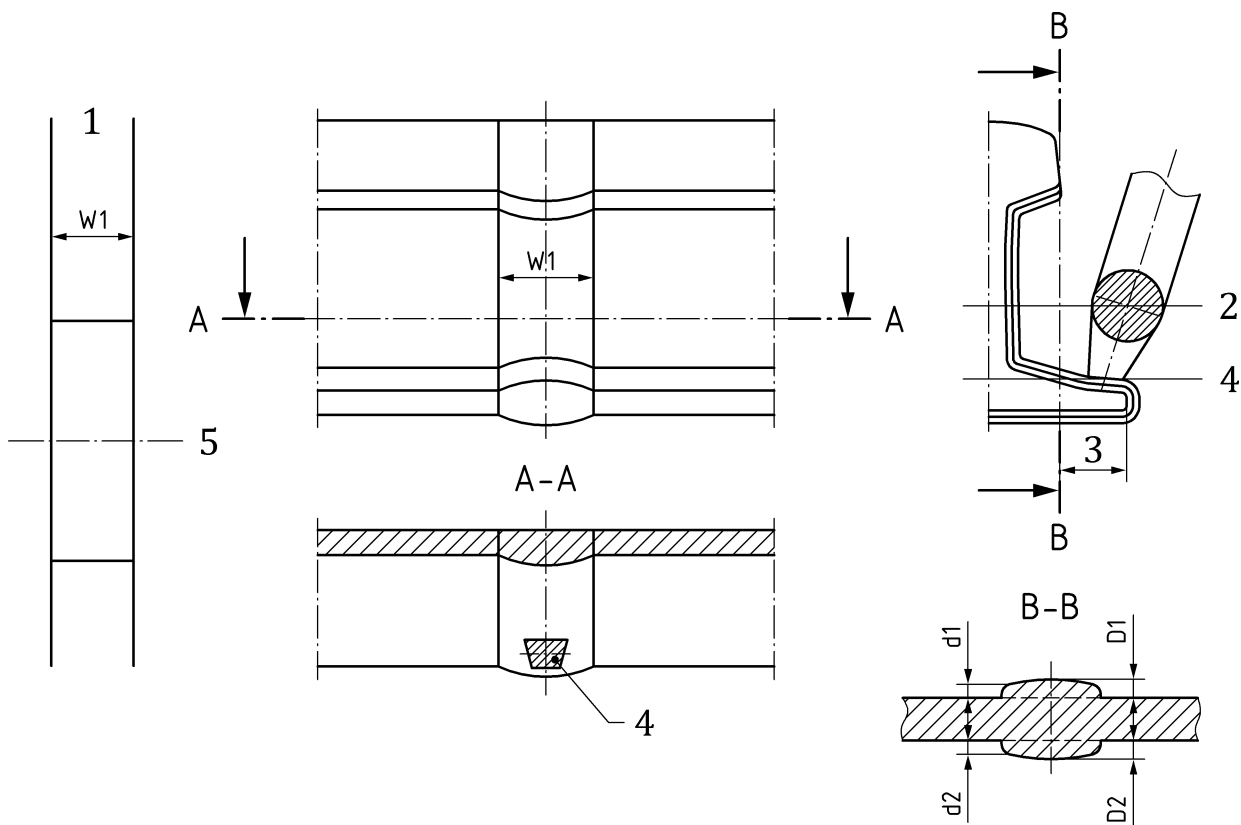
- a) number of people required to carry out the operations;
- b) diagram of equipment;
- c) portion for each rail grade and profile;
- d) rail end preparation requirements;
- e) nominal gap shall have a tolerance of:
 - ± 2 mm for a gap ≤ 30 mm
 - ± 3 mm for gaps > 30 mm and \leq to 50 mm
 - ± 5 mm for gaps > 50 mm
- f) preheating details;
- g) range of ignition to tap times for the portion;
- h) critical process timings;
- i) time (or temperature) before trains can pass;
- j) safety information.

5.4.2 Drawing with the required measurements

A drawing, as illustrated in Figure 1, which provides the measurements listed below:

- a) weld collar width ($W1$). The development of the weld collar shall be fully dimensioned around the weld;
- b) maximum depth of collar at section B-B ($D1$ and $D2$);
- c) minimum depth of collar at section B-B ($d1$ and $d2$);
- d) riser cross section at foot;
- e) riser cross section at neutral axis;
- f) number of risers;
- g) position of risers.

The dimensions $W1$, $D1$ and $d1$ and cross sectional areas of the risers shall be the nominal dimensions taken from the drawing of the pattern used to produce the moulds.



Key

- 1 Figure showing the width of the weld collar ($W1$) around the weld
- 2 Riser cross section on the neutral axis mm²
- 3 25 % of the foot width
- 4 Riser cross section at the foot mm²
- 5 Longitudinal axis under the rail foot

Figure 1 — Dimensions taken from mould pattern

5.4.3 Chemical analysis ranges and tolerances

The chemical analysis ranges and tolerances shall be in accordance with 7.6.

5.5 Initial compliance testing

- a) For the purposes of approval the standard rail profiles (see EN 13674-1) shall be grouped as follows:

Table 1 — Rail profile groups

Group	Rail profiles
1	60E1, 60E2
2	54E1, 54E2, 54E3, 54E4, 54E5, 55E1, 56E1
3	46E1, 46E2, 46E3, 46E4, 49E1, 49E2, 49E3, 49E5, 50E1, 50E2, 50E3, 50E4, 50E5, 50E6, 52E1

- b) Initial compliance with the present standard shall be achieved by undertaking the tests specified in category 1 of Table 2 using grade R260 rail of one profile in group 1 of Table 1. Compliance with all the criteria specified and with the railway authority's documented requirements specified in Clause 4 shall be demonstrated. A test sequence is outlined in informative Annex B. A test specimen can be used for several different tests.

Table 2 — Testing scheme

Test	Section reference	Number of tests		
		Category 1 ^a	Category 2 ^b	Category 3 ^c
		R260 only	R260 only	R200/R220/R260Mn/R350HT/ R320Cr/R350LHT/R370CrHT/R400HT
A Hardness Test	7.2	6	Nil	6
B Surface Examination – Visual	7.1.1 7.1.2	All	All	All
C Visible Heat Affected Zone	7.1.3	2	2	2
D Slow Bend Test	7.3	6	2	4
E Ultrasonic Inspection – Annex G	7.4.1	5	2	Nil
F Fatigue Test (Optional)	7.5	n*	Nil	Nil
G Fusion Zone – Weld Soundness	7.3 7.4.1 7.5	(6) 5 (n*)	(2) 2 Nil	(4) Nil Nil

H Fusion Zone – Shape and Dimensions	7.4.2	5	2	Nil
I Chemical Analysis	7.6	3	Nil	2
J Heat Softened Zone – Hardness Distribution	7.4.4	2	2	2
K Structure – Visible Heat Affected Zone – Fusion Zone	7.4.3 7.4.4	1 1	Nil Nil	1 1
Minimum number of welds		11 + n*	4	6

NOTE 1 n* indicates the number of welds required for one staircase or past the post evaluation. Typically, 10 test pieces will be required for a staircase and 3 for a past the post evaluation.

NOTE 2 () indicates weld soundness evaluation of the fracture face of the slow bend test or fatigue specimens.

^a Category 1: initial tests to be conducted using R260 grade rail and one profile from rail profile Group 1 (Table 1). Tests carried out on one profile, approves the other profile of that group

^b Category 2: tests to be carried out on one profile from each of the remaining rail profile groups (R260) in order to extend approval to that group

^c Category 3: For each other rail grade the tests specified in category 3 shall be conducted on one profile of group 1 or group 2 in order to extend the approval to all profile groups already covered by category 2 tests.

5.6 Extension of initial compliance testing

Initial compliance can be extended as follows.

The relevant railway authority requirements defined in Clause 4 a) to c) shall be met for each of the items below:

- a) For other groups of rail profiles in Table 1, the tests given in category 2 of Table 2 shall be conducted on only one profile from each of the appropriate groups to approve the whole group.
- b) For other rail grades by the tests in category 3 of Table 2 [5.5 b)], failure of any test shall cause non-compliance for that rail grade. Tests on one rail profile cover all profiles in categories 1 and 2.

5.7 Preparation and allocation of test welds

- a) Welding gap shall be measured after weld alignment (peaking) on both sides of the rail head (or on the running surface), web mid point and both foot tips. The maximum gap is the maximum at any of the above points and minimum the minimum of any of the above points.
- b) The weld gap for all welds made for Table 2 tests shall be within the specified range. In the case of the welds required for test H in category 1 of Table 2, three welds shall be produced at the minimum gap and two at the maximum, and for category 2 of Table 2, one weld at the maximum gap and one weld at the minimum gap.

- c) The number of each test shall be in accordance with the appropriate parts of Tables 2 and 3. The process supplier shall determine the order of testing.
- d) Where tests fail to meet the required test criteria as a result of a defect (or defects) in the rail, re-tests shall be made on a one-to-one basis.

6 Re-approval following process changes

6.1 Changes requiring approval

6.1.1 Geometric parameters

— Any geometric parameters given in 5.4.2:

- a) weld collar width (W);
- b) collar depth (D);
- c) collar depth (d);
- d) riser cross-section – in foot;
- e) riser cross-section – in neutral axis;
- f) riser configuration – position;
- g) riser configuration – numbers.

A revised drawing shall be submitted.

6.1.2 Crucible system

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

6.1.3 Tapping system

- Any changes in the chemical nature of the main component of the refractory of the tapping system body;
- Any changes in the geometry of the tapping system body as specified in the original drawing of the supplier.

6.1.4 Pre-heating system

- Any change in the equipment or critical parameters;
- Any change of pre-heating fuels (oxidising or reducing);
- Any change in working pressure or pre-heating times outside the ranges originally specified.

6.1.5 Portion

- Changes in the weight outside of the production tolerances and changes in the ranges of elements specified by the process supplier (see Annex A).

6.1.6 Welding gap

Initial approval involves testing a welding process at either end of the ranges specified in 5.4.1 e).

If the maximum gap proposed exceeds the maximum covered by the initial approval, testing is required at the new maximum gap. If the minimum gap proposed is less than the minimum covered by the initial approval, testing is required with new minimum gap.

Measurement of the gap shall be made as defined in 5.7 b).

6.2 Test requirements for re-approval following process changes

- a) Where the proposed change lies within the range or ranges given in Table 3, the tests shall be undertaken as detailed in Table 3. The change shall be approved if the acceptance criteria for each of the required tests are met. In-house laboratory facilities shall be approved by the railway authority.
- b) Changes which fall outside the limits of the range or ranges given in Table 3 (6.1.1 a) to 6.1.1 f)) shall only be approved if they meet the requirements for demonstrating initial compliance as given in Table 2.
- c) In the case of the combination of multiple changes, the number of tests to be undertaken will be the largest number required in each column of Table 3 for these particular changes. e.g. combining changes to the pre-heating system and welding gap shall require 6 of test A (not 12), 1 of test C, etc..
- d) Re-approval following the process changes detailed in Table 3 shall be made in one profile of group 1 of Table 1 and rail grade R260 and shall be valid for all profile groups and grades of the existing approval.
- e) Failure of the relevant tests of Table 3 shall cause non-compliance of the process change.

Table 3 process changes

Test	In house ^a	Range or modification	External ^b										Total number of welds required
			Number of tests (Test as defined in Table 2)										
			A	C	D	E	F	G	H	I	J		
			Centreline hardness	Visible HAZ	Slow bend test	Ultra-sonic test	Fatigue test	Weld soundness	Fusion width	Chemical analysis	HAZ hardness		
6.1.1 a) Weld collar width W	±3mm	±10mm	-	-	4	-	4	4	4	-	-	4	
6.1.1 b) Collar depth (D)	±2mm	±6mm	-	-	4	-	4	4	4	-	-	4	
6.1.1 c) Collar depth (d)	±2mm	±4mm	-	-	4	n ^c	4	4	4	-	-	4 + n ^c	
6.1.1 d) Riser cross-section – Foot	±10 %	±30 %	-	-	4	-	4	4	4	-	-	4	
6.1.1 e) Riser cross-section – Neut. axis	±10 %	±40 %	-	-	4	-	4	4	4	-	-	4	

6.1.1 f) Riser config. – Position	+5mm	+10mm	-	-	-	-	-	-	-	6	-	-	4	6	-	-	-	10
6.1.1 g) Riser config. – Numbers	-	All	-	-	-	-	-	-	-	6	-	-	4	6	-	-	-	10
6.1.2 Crucible system	-	All	-	-	-	-	-	-	-	6	-	-	-	6	3	-	-	6
6.1.3 Tapping system	-	All	-	-	-	-	-	-	-	6	-	-	4	6	3	-	-	10
6.1.4 Pre- heating system	-	All	6	1	6	-	-	-	-	6	-	-	4	6	-	2	-	10
6.1.6 Welding gap	-	All	6	1	6	-	-	-	-	6	-	-	4	6	-	2	-	10

^a In house – Conducted by the process supplier

^b External – Conducted by a test house approved by the railway authority

^c n: One staircase or past the post evaluation. Typically, 10 test pieces will be required for a staircase and 3 for a past the post evaluation

7 Laboratory tests

7.1 Visual surface examination

7.1.1 As-cast weld surface

Following stripping and final grinding the as-cast weld collar surface shall be visually examined for soundness. For the process to be accepted:

- there shall be no cracks with length of 2 mm, or greater. Joints between weld collars and rail and flashing and rail are not cracks;
- 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 to 3 mm per test piece excluding flashing;
- slag or sand inclusions shall not exceed the limits set in Table 4. No defect shall intrude into the rail cross section nor touch the edge of the weld collar/rail intersection;

Table 4 — Maximum dimensions of slag or sand defects

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

- the condition of the surface left by riser removal (other than that on the ground rail head) shall conform with the requirements specified in the information supplied by the railway authority.

7.1.2 Ground weld surface

Both side of the ground rail head shall comply with the following:

- There shall be no defects (cracks, pores, slag, sand inclusions, metal beads) with a dimension greater than 1 mm.

7.1.3 Visible heat affected zone

Following Fry etching in accordance with Annex C the visible heat affected zones on each side of the weld shall be measured on the rail running surface centre line. The visible heat affected zone shall be symmetrical about the longitudinal axis of the rail and transverse axis of the weld.

7.2 Running surface hardness test

Measurements shall be made in accordance with Annex D. These shall be carried out on the flat ground surface (Figure D.1) before final profile grinding takes place.

The average of the three hardness measurements made on each weld shall fall within the range given in Table 5 for the appropriate parent rail grade.

Table 5 — Ranges for running surface hardness tests

Rail grade	Hardness range HBW	
	Rail running surface on the unaffected parent rail	Weld centre-line
R200	200 to 240	230 ± 20
R220	220 to 260	250 ± 20
R260	260 to 300	280 ± 20
R260	260 to 300	300 ± 20
R260Mn	260 to 300	280 ± 20
R320Cr	320 to 360	330 ± 20
R350HT	350 to 390	350 ± 20
R350LHT	350 to 390	350 ± 20
R370CrHT	370 to 410	370 ± 30
R400HT	400 to 440	390 ± 30 ^a

^a A different hardness range is permitted for R400HT rail grade with the agreement of the appropriate railway authority.

NOTE The centre-line hardness of the welds for the chromium alloyed and for the heat-treated grades is established below the hardness values of the rail running surface to ensure a fully pearlitic structure. The hardness profile along the rail crown centre-line of welds varies with the level of alloying element additions, with higher alloyed welds showing a relatively higher hardness at the weld edges. Therefore to achieve the correct average hardness, a lower centre-line hardness is required.

7.3 Slow bend test

Details of the slow bend test procedure are given in Annex E.

The minimum fracture load (kN), rounded to the nearest 5 kN is defined by the formula $F = 0,0032 S$ (equivalent to a minimum tensile bending strength of 800 MPa), where S (mm³) is the section modulus for the base of the rail, given in EN 13674-1.

For R200 grade rail, a minimum tensile bending strength of 700 MPa is required. The formula $F = 0,0028 S$ shall be used for this purpose.

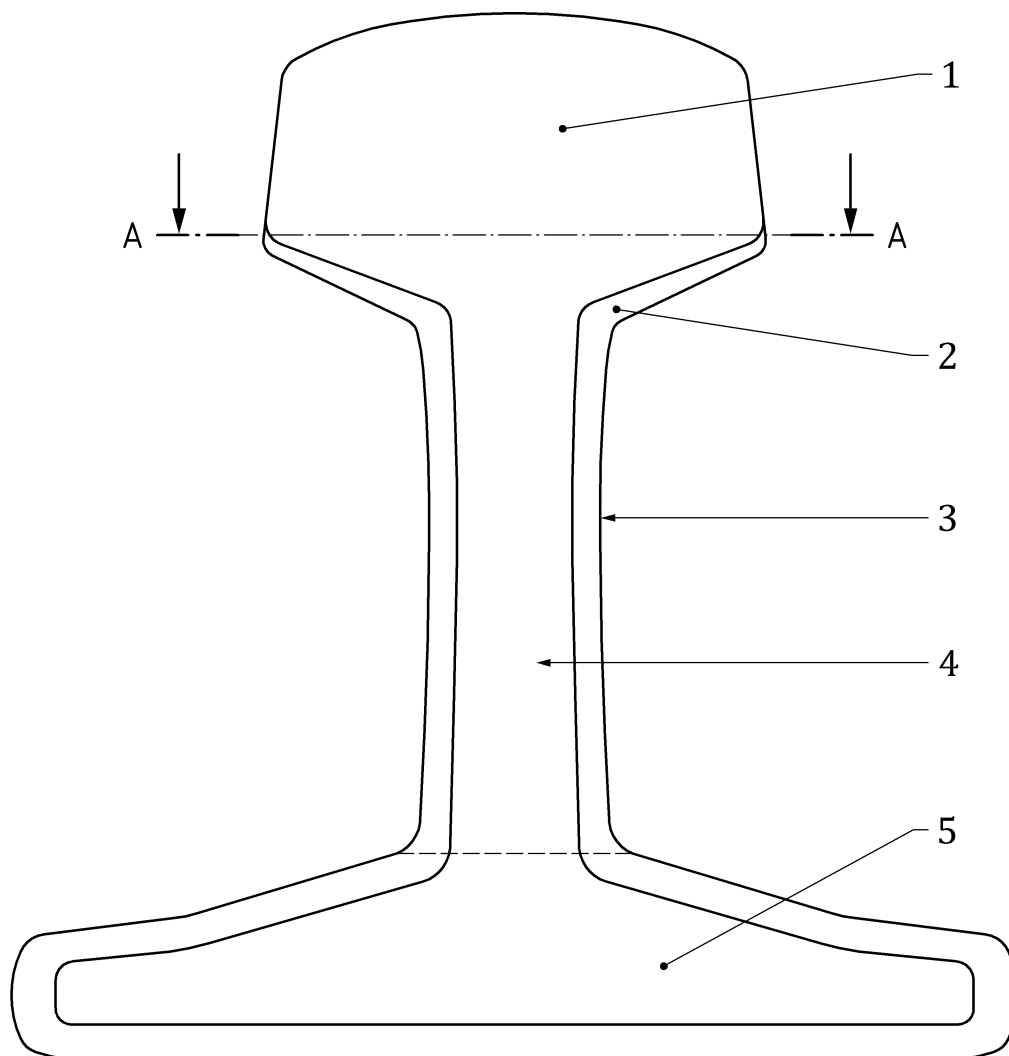
The formula $F = 0,003 S$ shall be used for R320Cr, R370CrHT and R400HT rail grades.

The fracture face shall be subject to the soundness examination in accordance with 7.4.1 and a record made in accordance with Annex F.

7.4 Internal examination

7.4.1 Weld soundness

Welds for ultrasonic inspection (test E in Table 2 and Table 3) shall be cut so that the head, web and foot of the rail containing the weld (see Figure 2) can be examined ultrasonically in accordance with Annex G. The positions of any apparent defects found by ultrasonic testing shall be recorded so that they may be revealed by sectioning. Cuts shall be positioned at least 5 mm from any apparent defects located by the ultrasonic testing method specified in Annex G. For each defect, the size shall be determined by progressively grinding or machining and measuring until the maximum dimension is found.



Key

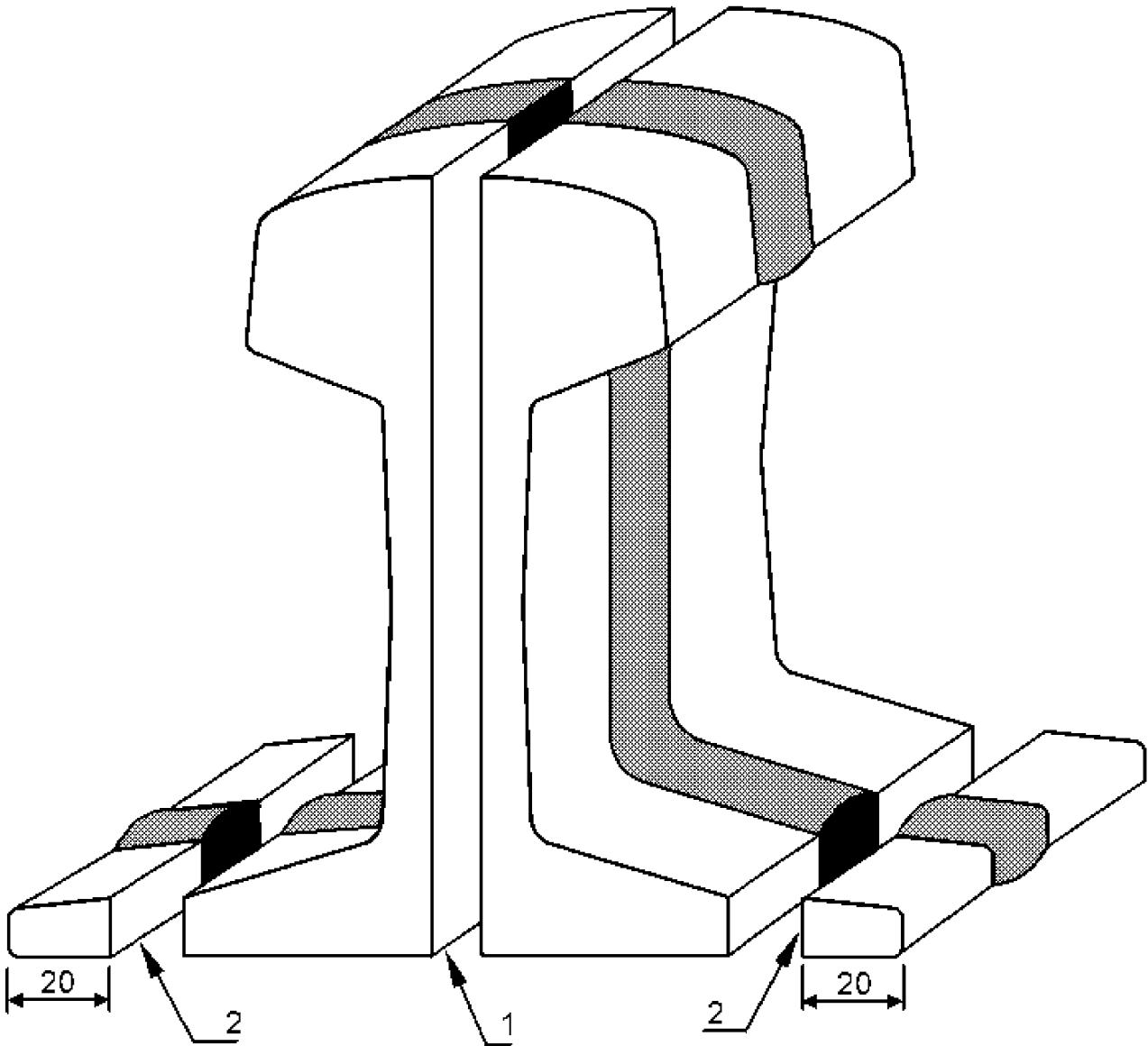
- 1 Head
- 2 Profile of rail
- 3 Profile of weld
- 4 Web
- 5 Foot

Figure 2 — Transverse section of head, web and foot of the rail

The rails containing the welds shall then be sectioned to give:

- longitudinal vertical section on the symmetry plane (cut 1 in Figure 3);
- longitudinal vertical sections in the rail foot (cuts 2 in Figure 3).

Dimension in millimetres



Key

- 1 Longitudinal vertical section on centre line
- 2 Longitudinal vertical section of foot tip

Figure 3 — Sectioning of Welds

Visual examination of the cut sections (polished to 220 grit) shall show no evidence of lack of fusion between the rail and fusion face.

The weld collar's edge is permitted to be unfused to the rail surface for a maximum of 2 mm from the edge of the collar unless a lesser figure is specified in the information supplied by the railway authority (see 4b).

The maximum dimension of any pores, slag inclusions, sand inclusions or metal beads shall be recorded. If multiple defects are revealed, they shall be counted and measured as a single defect if they are less than 1 mm apart:

- no more than one defect with maximum dimension greater than 2 mm in the region of the head above the line A-A on Figure 2 shall be permitted.

NOTE 1 The information on weld soundness collected by the requirements of this subclause is used for reference in the appropriate tests of Clause 6 required for process changes.

NOTE 2 Areas containing micro-porosity or inter-dendritic shrinkage are not counted as single defects and therefore are not taken into consideration.

Fracture faces revealed by the slow bend test specified in 7.3 and each of the fatigue test pieces specified in 7.5 shall be examined visually and a record made, in accordance with Annex F, of the maximum dimensions of any pores, slag inclusions, sand inclusions or metal beads.

Per population of test welds in test G in Table 2 and Table 3:

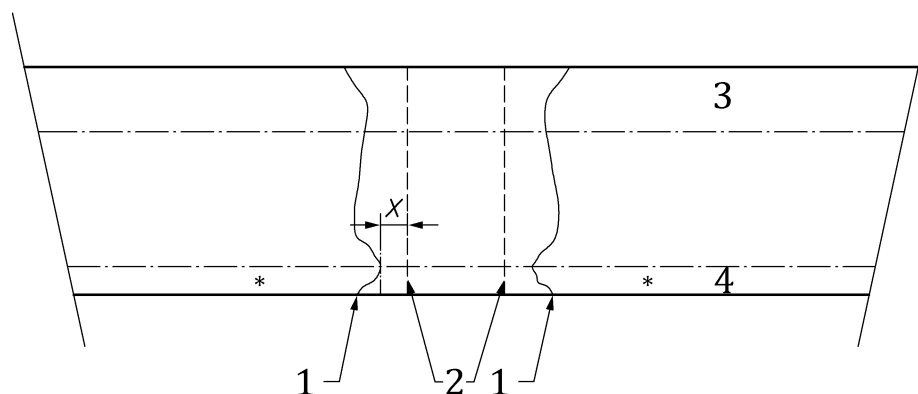
- no more than one volumetric defect with maximum dimension greater than 2 mm in the region of the head above the line A-A on Figure 2 shall be permitted.

7.4.2 Fusion zone – Shape and dimension

Following Fry etching in accordance with Annex C, measurement of the fusion zone shall be made on the cuts illustrated in Figure 4.

The minimum distance X (Figure 4) between the parent rail ends before welding and the fusion line shall be equal to or greater than 3 mm.

Measurement of X shall be made using datum marks to locate the original position of the rail ends.



Key

- * Datum marks
- 1 Fusion line
- 2 Rail ends before welding
- 3 Rail head
- 4 Rail foot

Figure 4 — Shape of fusion zone on the etched longitudinal vertical section

The fusion zone shall exhibit a symmetrical shape about the welding gap.

7.4.3 Fusion zone

The structure of the fusion zone shall conform with that defined by the process supplier, which shall not include martensite or bainite at $\times 100$ magnification. In special cases the railway authority may permit a fully bainitic structure. The structure shall be recorded.

7.4.4 Heat softened zone width

The procedure for measuring the width of the heat softened zone is given in Annex I.

The heat softened zone on either side of the weld shall have one of the following widths which shall comply with the information supplied by the railway authority [Clause 4, b)].

Table 6 — Ranges of heat softened zone

Less than or equal to	Heat treated rail	Non-heat treated rail
20 mm	✓	✓
30 mm	✓	✓
40 mm	✓	✓
50 mm	✓	-
60 mm	✓	-

7.5 Fatigue test

Fatigue strength shall be evaluated by the staircase or past the post procedure in accordance with Annex J.

The fatigue requirement in terms of the mean fatigue strength for the staircase method of testing or the minimum value of fatigue strength for past the post testing shall comply with the information supplied by the railway authority [Clause 4 c)].

For staircase testing the fracture faces of those welds broken during fatigue testing shall be examined visually. If fatigue has initiated at a lack of fusion defect, the process shall be rejected.

The fracture faces of all welds, however broken, shall be examined for soundness in accordance with 7.4.1.

7.6 Chemical analysis

The process supplier shall define the mean value for each element with a working range in Table 7. Actual values shall not vary by more than the working range and this range shall fit within the permitted range.

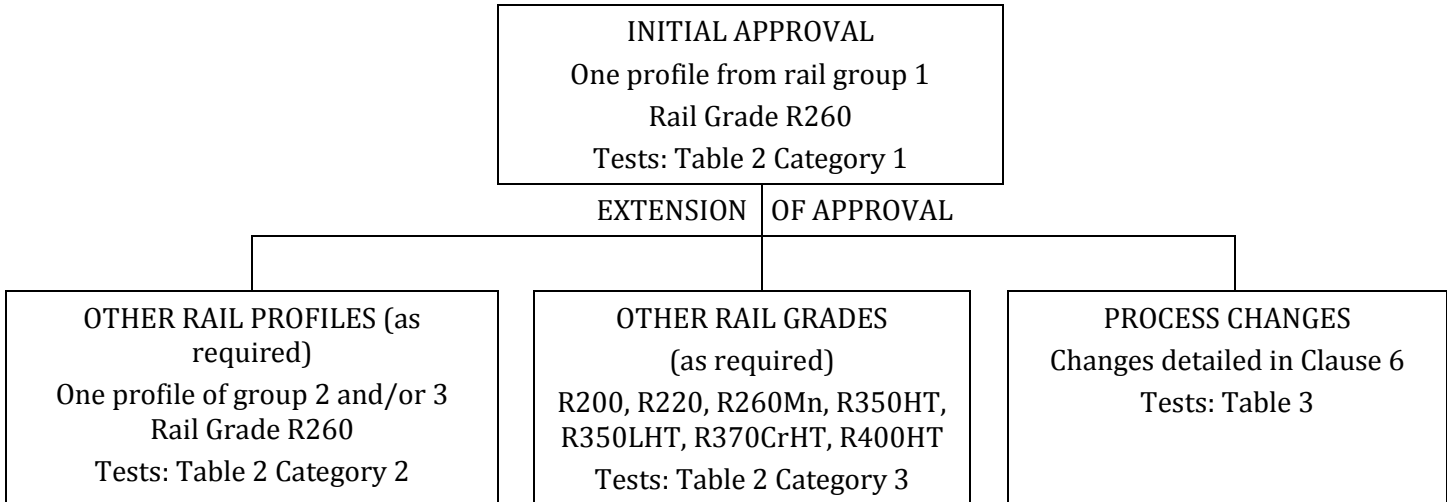
Chemical analysis is to be conducted on the rail weld running surface in the fusion zone at least 5 mm from the weld transverse axis and at least 5 mm from the limit of the fusion zone. Results of analysis shall fall within the ranges specified by the process supplier.

Table 7 — Chemical composition

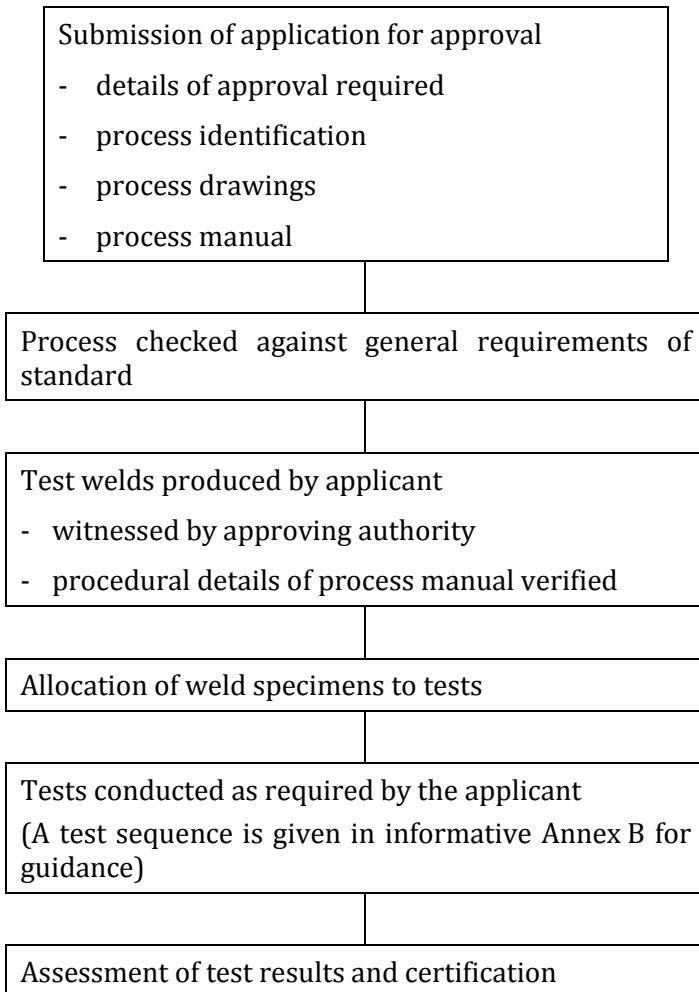
Element	Permitted range %		Working range	Rail grade EN 13674-1
	Minimum	Maximum		
Carbon	0,30	0,55	±0,12	R200
	0,35	0,70	±0,12	R220
	0,40	0,75	±0,12	R260, R260Mn
	0,50	1,00	±0,12	R320Cr, R350HT, R350LHT
	0,50	1,20	±0,15	R370CrHT, R400HT
Silicon	0,00	1,75	±0,25	All
Manganese	0,40	1,00	±0,20	R200
	0,45	1,20	±0,20	R220
	0,50	1,40	±0,20	R260, R320Cr, R350HT, R350LHT
	0,50	1,60	±0,20	R260Mn, R370CrHT, R400HT
Phosphorous	0,00	0,035	—	All
Sulfur	0,00	0,035	—	All
Chromium	0,00	0,20	—	R200, R220, R260, R260Mn
	0,00	0,80	±0,20	R320Cr, R350HT, R350LHT, R370CrHT, R400HT
Molybdenum	0,00	0,40	—	All
Nickel	0,00	0,20	—	All
Aluminium	0,02	0,60	±0,20	All
Copper	0,00	0,20	—	All
Tin	0,00	0,02	—	All
Antimony	0,00	0,02	—	All
Titanium	0,00	0,05	—	All
Niobium	0,00	0,02	—	All
Vanadium	0,00	0,25	—	R200, R220, R260, R260Mn
	0,00	0,45	—	R320Cr
	0,00	0,65	—	R350HT, R350LHT, R370CrHT, R400HT

Annex A
 (informative)

Steps in approval

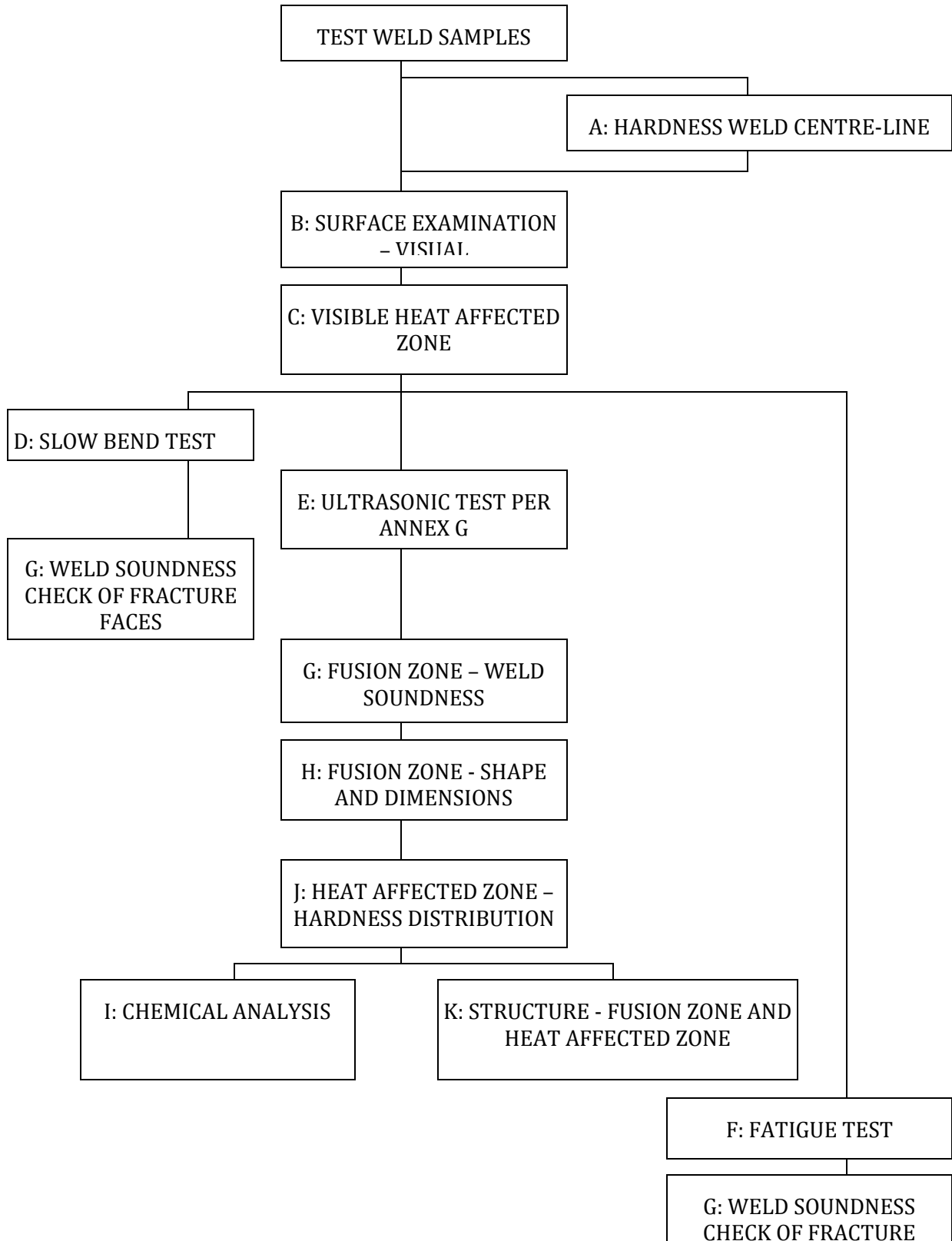


Each of the above steps will be achieved by the following sub steps:



Annex B
(informative)

Suggested sequence of laboratory test



NOTE The boxes specify the tests outlined in Table 2.

Annex C (normative)

Procedure for Fry etching

Many of the macrostructure characteristics are measured following Fry etching which is conducted using the following method.

The etching agent should have the following chemical composition (for 10 ℓ):

- 1,875 kg cupric chloride ($\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$);
- 5 ℓ hydrochloric acid (HCl 1,18 g/ml – 35 %);
- 4,2 ℓ water.

Macro-etching at room temperature shall be for sufficient time (minimum 30 min) to clearly show the boundary lines. Sample shall be polished with minimum 220 grit paper.

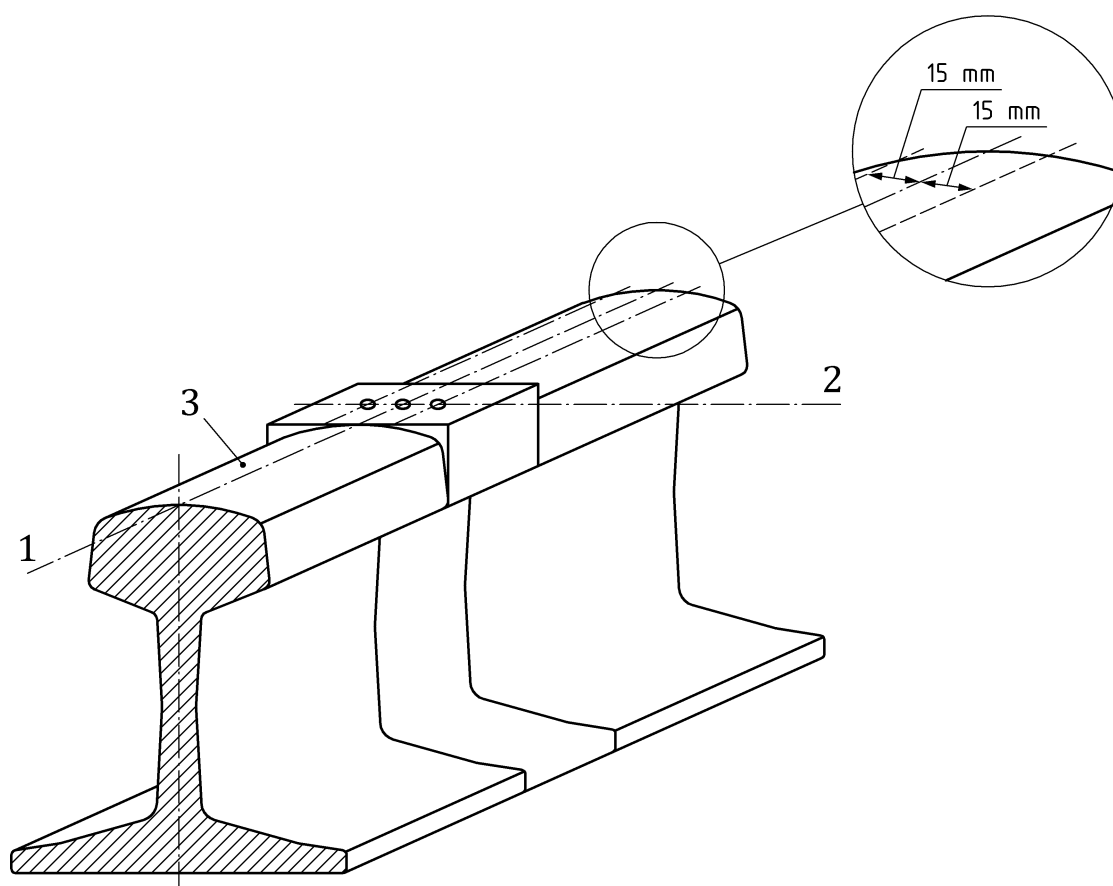
Annex D (informative)

Procedure for measurement of surface hardness

Brinell hardness tests shall be carried out in accordance with EN ISO 6506-1 using:

- 5 mm or 10 mm diameter tungsten carbide ball;
- test load 750 kg (5 mm diameter ball) or 3000 kg (10 mm diameter ball);
- load application time of 15 s.

The top of the test weld shall be ground to produce a flat surface which is tangential to the rail crown at the point of intersection with the rail vertical axis in accordance with Figure D.1.



Key

- 1 Rail crown centre-line
- 2 Weld transverse centre-line
- 3 Rail running surface

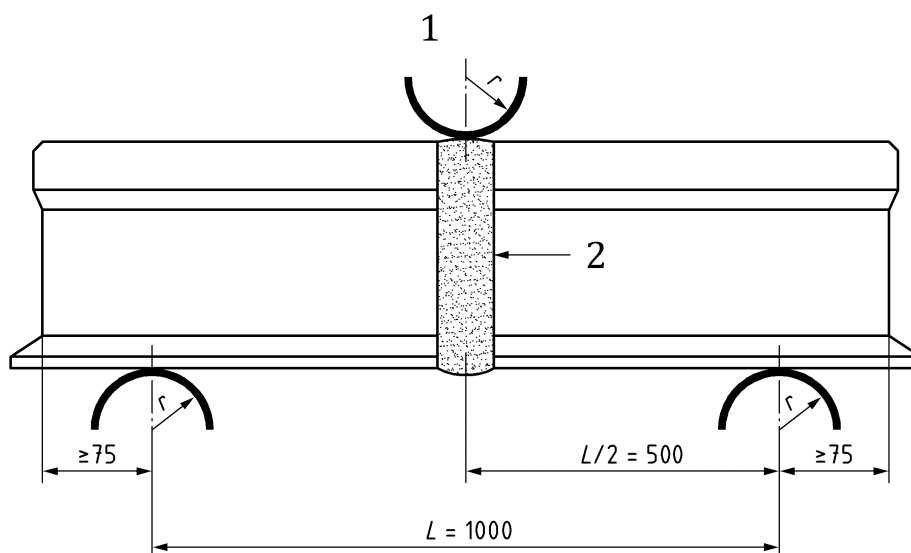
Figure D.1 — Location of surface hardness tests

Three hardness values shall be determined for each weld as shown in Figure D.1.

Annex E (normative)

Procedure for slow bend test

The key dimensions for the slow bend test apparatus are given in Figure E.1.



Key

1 Load

2 Weld

$25 \text{ mm} \leq r \leq 70 \text{ mm}$

Minimum sample length = 1150 mm

Loading rate $\leq 60 \text{ kN/s}$

Figure E.1 — Slow bend test schematic

The load shall be applied to the running surface of the weld by a single fulcrum. The test shall continue until fracture.

Annex F (normative)

Procedure for recording test weld fracture face defects

A record of any defects found on the fracture face of each weld shall be made on a rail profile grid (Figure F.1). The record shall include the following details:

- type of defect;
- surface dimensions;
- shape;
- location;
- depth of pores.

The record will show the test weld identification and whether the weld was used for slow bend or fatigue testing.

A weld fracture face containing no defects shall have the rail profile grid clearly worded “No visible defects”.

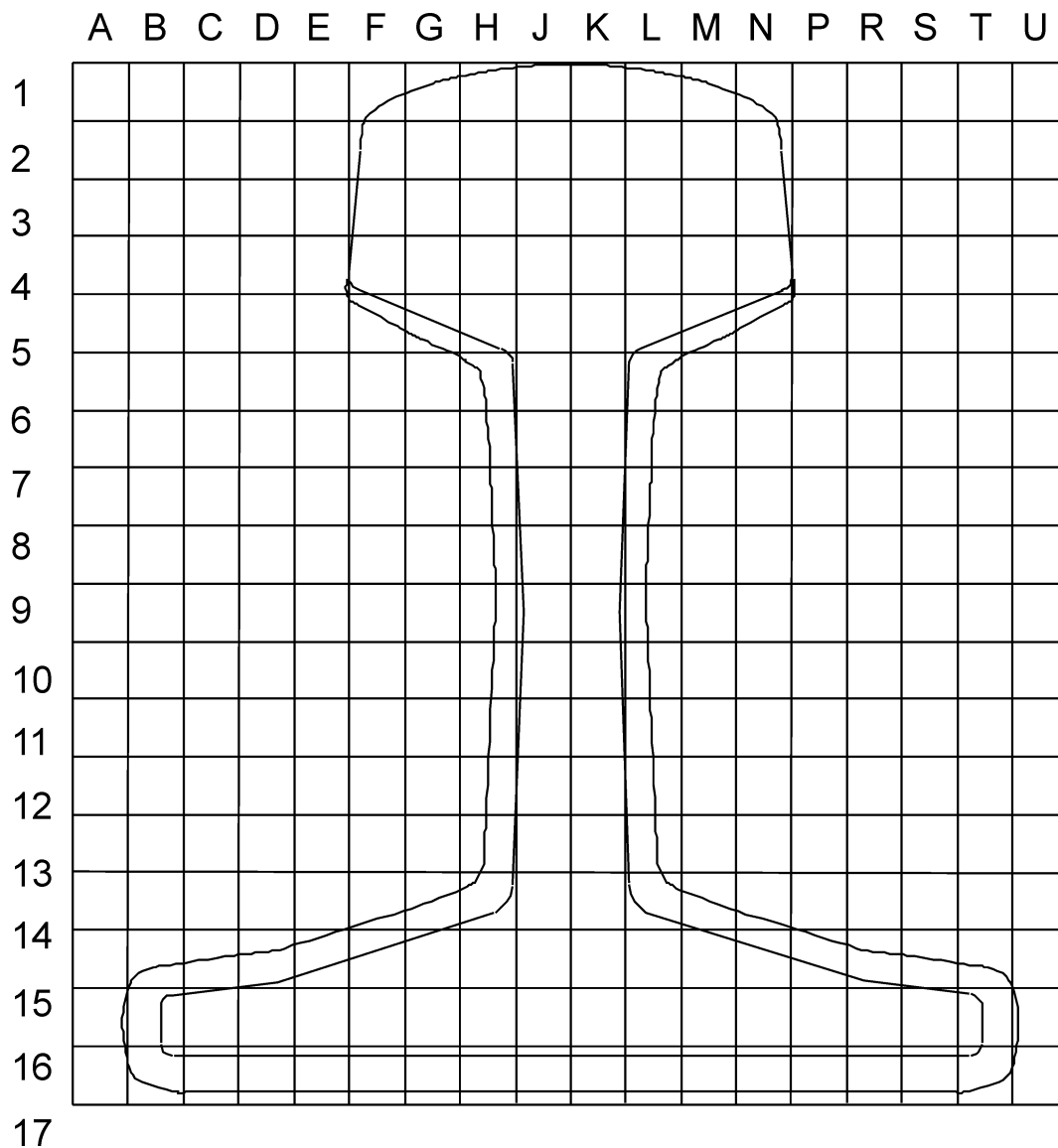


Figure F.1 — Rail profile grid

Annex G (normative)

Ultrasonic inspection procedure on aluminothermic welds to be sectioned

G.1 General

This procedure concerns the use of an ultrasonic method for examination of aluminothermic welds in rail specimens to be sectioned. The method is able to detect transverse-vertical 'lack-of-fusion' defects, large gas pores and 'hot tears' caused by rail movement. This procedure shall establish the location of defects relative to the rail cross-section and shall provide an estimation of their transverse extent. If more accurate sizing is required, other ultrasonic procedures shall be applied. Personnel using this procedure shall be qualified to EN ISO 9712.

G.2 Test equipment

For the test are required:

- an ultrasonic instrument approved by the Railway Authority;
- double crystal, 0° compression wave probe, of 20 mm diameter and frequency 4 MHz to 5 MHz;
- metric universal calibration block for general purpose checking.

G.3 Preparation of samples

A section of rail containing the aluminothermic weld shall be prepared by making two transverse cuts, one on each side of the weld at equidistant spacing from the edge of the weld collar. The cuts shall be perpendicular to the longitudinal axis of the weld, parallel to each other and to the weld collar. The length between the cut faces shall be between 180 mm and 200 mm in the case of standard-width welds and between 210 mm and 230 mm in the case of wide-gap welds (more than 30 mm nominal gap size).

G.4 Adjustment

Timebase – using the metric calibration block calibrate the timebase of the flaw detector.

For aluminothermic welds with nominal gap sizes up to 30 mm, the timebase shall be calibrated to 10 mm per scale division (i.e. 400 mm full screen width).

For aluminothermic welds with nominal gap sizes above 30 mm, the timebase shall be calibrated to 20 mm per scale division (i.e. 400 mm full screen width).

Sensitivity – place the probe on one of the surfaces of the cut sample and obtain a signal from the opposite face. Adjust the gain level until the signal is at 100 % of full screen height. The sensitivity level shall be reset for each face of each sample tested.

G.5 Testing

Place the probe on one of the transverse-cut faces and obtain the full screen height signal from the opposite parallel face. Scan the whole area of the rail section and note the presence of any signals and any zones where the signal from the opposite face falls below 50 % of full screen height.

If a signal or a decrease in backwall signal is detected, determine the limits of the defective zone by probe movement and mark these limits on the face being scanned.

If signals are detected, use the timebase to determine their depth below the scanned surface. In each case note the depth and note the amplitude of the signal.

Repeat the scan from the other transverse-cut face.

G.6 Reporting

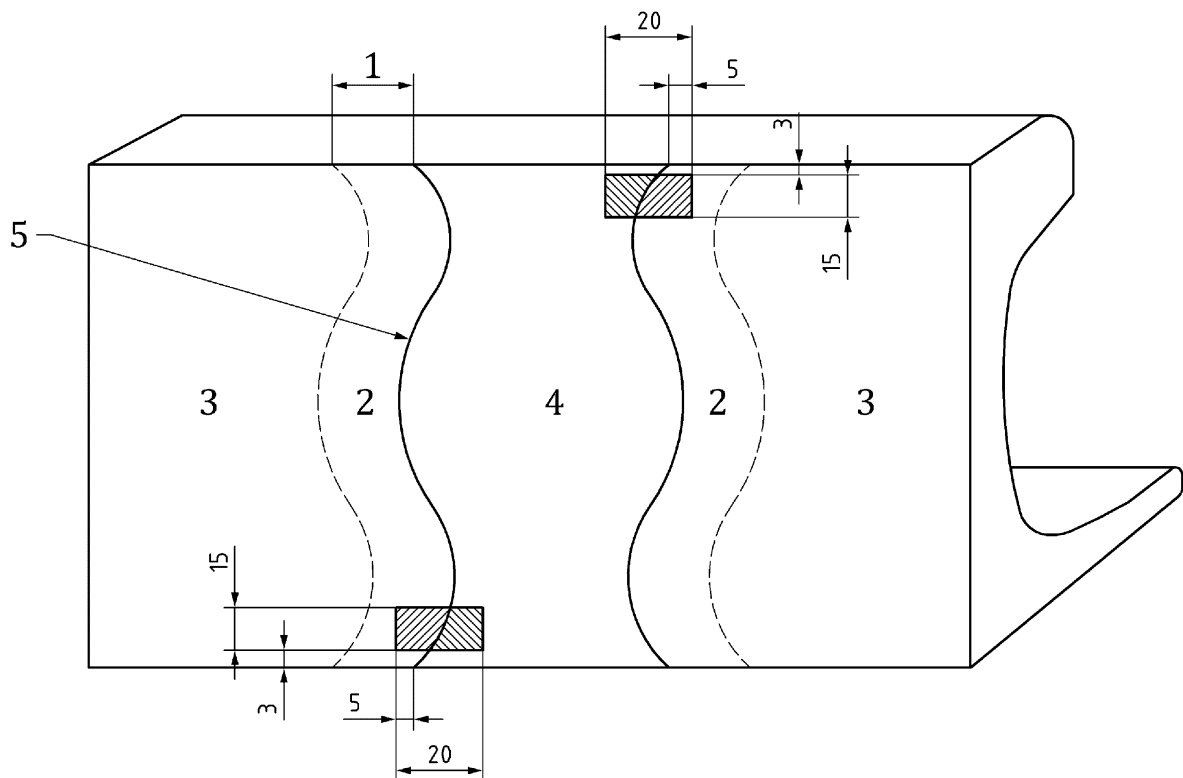
The extent and depth of any defect found shall be marked and shall be reported on the sample and reported for further investigation.

Annex H (normative)

Procedure for microscopic examination of the visible heat affected zone and fusion zone of welds

Samples for microscopic examination shall be taken in accordance with Figure H.1. The samples shall be prepared and etched in 4 % Nital.

Dimensions in millimetres



Key



- 1 Width of the visible heat affected zone to be measured at the weld longitudinal centre line of the running surface
- 2 Visible heat affected zone
- 3 Unaffected parent rail
- 4 Weld fusion zone
- 5 Fusion line
-  Area of fusion zone to be examined microscopically
-  Area of visible heat affected zone to be examined microscopically

Figure H.1 — Scheme for taking samples for microscopic examination

Annex I (normative)

Procedure for measurement of the heat softened zone width

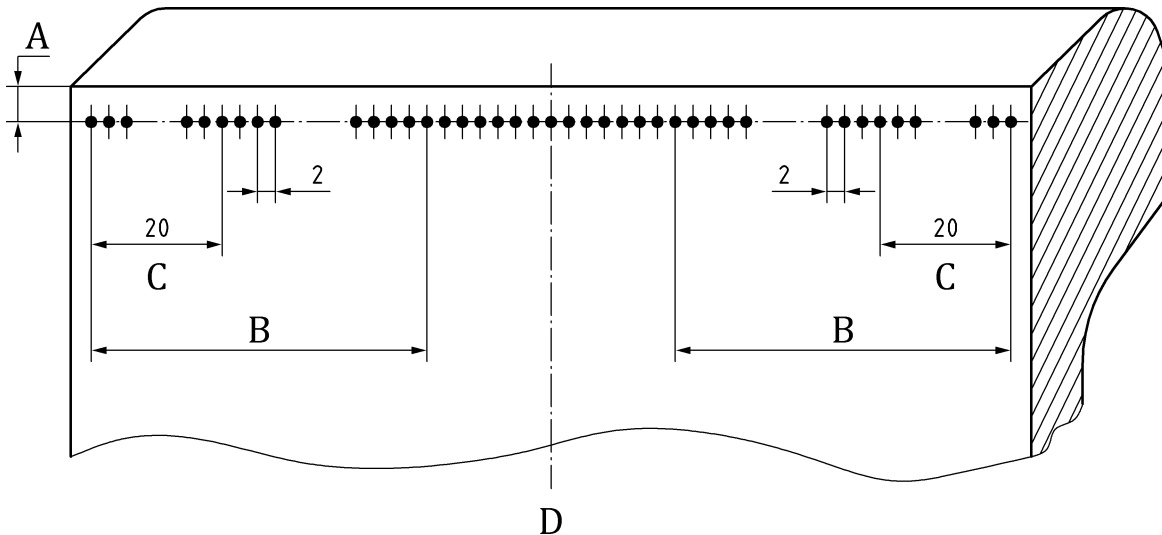
I.1 Measurement of hardness

The hardness distribution of the heat softened zone shall be measured using the Vickers hardness test in accordance with EN ISO 6507-1 and a load of 30 kg.

Impressions shall be on a line between 3 mm and 5 mm below the rail running surface on the longitudinal axis of the rail. Alternatively, impressions may be taken on the running surface of the rail on the longitudinal axis after the rail has been machined to a depth of 3 mm.

The hardness traverse shall extend across and to both sides of the weld continuing until 20 mm of unaffected parent rail hardness has been encountered. Measurements shall be made at points 2 mm apart as shown in Figure I.1.

Dimensions in mm



Key

- A Depth between 3 mm and 5 mm
- B Parent rail
- C Unaffected parent rail
- D Weld centre line

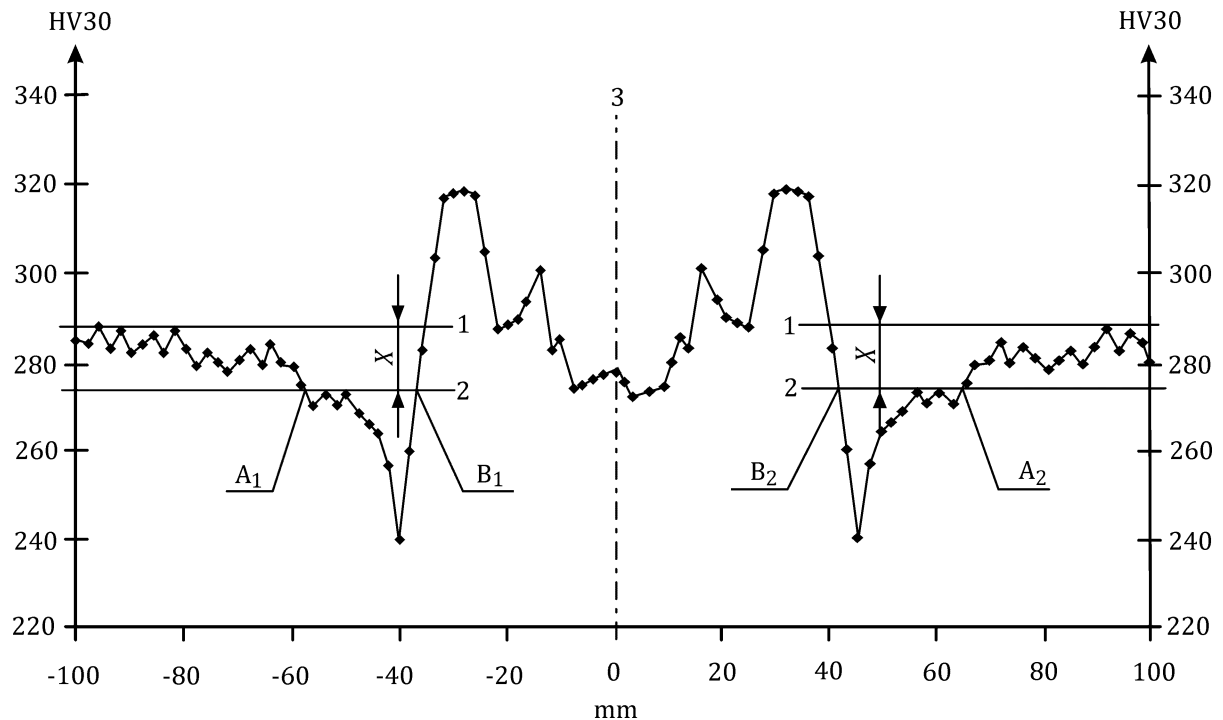
Figure I.1 — Longitudinal hardness measurement

Hardness measurements obtained shall be recorded numerically and graphically.

I.2 Evaluation of hardness data

I.2.1 General

Hardness measurements shall be graphically shown as in Figure I.2.



Key

- 1 Line 1
- 2 Line 2
- 3 Weld centre line

Figure I.2 — Typical hardness profile

I.2.2 Mean hardness of parent rail

The mean hardness of the parent rail on either side of the weld is calculated from a minimum of 10 hardness measurements taken at intervals of 2 mm in the unaffected parent rail. A line equal to the mean hardness is marked on the hardness graphs for each side of the weld as shown (Line 1).

I.2.3 Measurement hardness line

The measurement hardness line (Line 2) is marked parallel to the mean hardness line, and at a distance of X hardness points below the mean hardness line. The value of X varies with the rail grade:

- $X = 10$ for: Grade R200, Grade R220, Grade R260, Grade R260Mn, Grade R320Cr
- $X = 25$ for: Grade R350HT, Grade R350 LHT, R370CrHT, R400HT

I.2.4 Heat softened zone width measurement

The heat softened zone width is defined as the distance between points A1,2 and B1,2 in Figure I.2 above.

I.2.5 Parent rail hardness variation

In some cases the unaffected parent rail may have a large standard deviation of hardness about the mean. This may 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 can be ignored if a) and b) apply:

- a) no more than one hardness point of those used to define the parent rail mean hardness lies below Line 2;
- b) the hardness point lying below Line 2 is more than 4 mm from Point A of Figure I.2.

Annex J (normative)

Fatigue test methods for aluminothermic welds

J.1 General

This annex describes the staircase test method (see J.4.2) to establish the fatigue strength distribution of a weld at an endurance of 5 million 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.

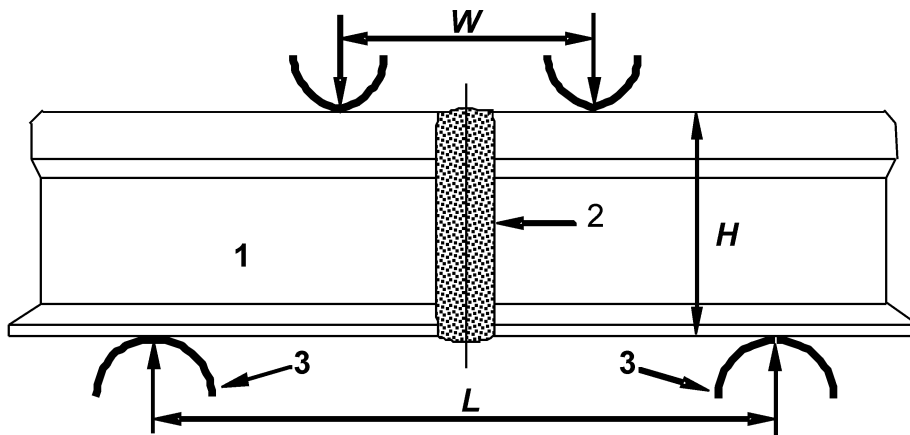
The past-the-post method (see J.4.4) is also described for testing three welds, none of which shall break at a defined cyclic stress level.

J.2 Test equipment

Tests shall be conducted in four point bending with the rail foot in tension.

The inner span (W) shall be a minimum 150 mm plus weld collar width under the foot. The outer span (L) shall exceed the inner span by at least twice the rail height (H) and shall be symmetrical about the inner span:

$$L \geq W + 2 \cdot H \tag{J.1}$$



Key

- 1 Rail
- 2 Weld
- 3 Support

Figure J.1 — Fatigue test arrangement

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 should not differ by more than 3 mm.

The radius of curvature of the loading points shall not be less than 40 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.

NOTE 1 High contact stresses may result in cracks developing at the loading points. The use of arrangements that minimize contact stresses at the loading points is therefore advised. Contact stresses may be further reduced by increasing the outer span and so reducing the force required to achieve a given applied bending moment.

The applied force should be measured using a fatigue rated load cell verified to EN ISO 7500-1:2015, Grade 1.0.

NOTE 2 Depending on the outer span, a 500 kN or 1000 kN actuator is likely to be suitable for most applications.

J.3 Calibration procedure

The test rig shall be calibrated to ensure that the upper and lower limits of the outer fibre stress are achieved under the foot of the rail at the centre line of the weld collar.

J.4 Fatigue test results

J.4.1 General

The railway authority has the option according to Clause 4c) and 7.5 to select either a staircase (see J.4.2) or a past-the-post test (see J.4.4).

J.4.2 Staircase testing method

J.4.2.1 Test pieces

Ten test-pieces are required. 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.

J.4.2.2 Procedure

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.

1. Determine the maximum stress associated with the mean fatigue strength at 5 million cycles required by the railway authority.

EXAMPLE If the mean fatigue strength is to be not less than a stress range of 230 MPa when the ratio of the minimum to maximum applied stress (R) is 0,1; then the maximum stress will be $230/(1 - R) = 256$ MPa.

Determine the maximum force and the force range corresponding to these values of maximum stress and stress range.

2. Cyclically load the weld using a sinusoidal waveform so that the maximum value of force, and the range derived in 1) are achieved. The indicated maximum load and load range shall both be maintained to within 2 % of the nominal value required. Continue cycling until either the test piece breaks or 5 million cycles have been applied.
3. If the test piece breaks, the test result shall be recorded as a 'failure'. If it does not break, it shall be recorded as a 'run-out'. The cyclic force range and nominal outer fibre stress range shall also be recorded.

4. Where the test results in a run-out, repeat the test on another test piece but increase the cyclic force range by an amount corresponding to an increase in the nominal outer fibre stress range in the foot of 10 MPa. Where the test result is a failure, repeat the test on another test piece with the maximum foot stress range reduced by 10 MPa. In both cases the minimum load applied shall be 10 % of the maximum.
5. Continue as above until 10 test pieces have been tested.

J.4.2.3 Data analysis

Results are all failures or all run-outs.

No data analysis is required.

- a) Both failures and run-outs obtained.

Estimate the mean value and standard deviation of the fatigue strength as follows.

Determine first of all whether failures or run-outs are the less frequent events. Then calculate the mean fatigue strength σ_m using the formula:

$$\sigma_m = \sigma_0 + d \cdot \left(\frac{A}{N} \pm 0,5 \right) \quad (\text{J.2})$$

where:

σ_0 lowest stress range at which tests with the less frequent result were conducted (MPa)

$d = 10$ MPa

$A = \sum i \cdot n_i$ where i ranges from 0 to z

$N = \sum n_i$ where i ranges from 0 to $z =$ total number of less frequent events

where:

$n_i =$ number of less frequent events at the i -th stress level above σ_0

$i =$ coded stress level ($i = 0$ for σ_0)

$z =$ number of stress levels above σ_0 at which testing has been undertaken

In the formula use $(A/N) + 0,5$ if the less frequent event is a run-out and $(A/N) - 0,5$ if the less frequent event is a failure.

Calculate the standard deviation using the formula:

$$s = 1,62 \cdot d \cdot \left(\frac{B \cdot N - A^2}{N^2} + 0,029 \right) \quad (\text{J.3})$$

where:

$B = \sum i^2 \cdot n_i$

b) Information to be reported

For each test series the following information shall be reported:

- the inner and outer spans of the test rig (J.2);
- the distances from the centre line of the actuator to the loading points (J.2);
- dynamic calibration results (J.3);
- the mean and standard deviation of the fatigue strength at 5 million cycles if calculated according to the procedure given in J.4.2.3 a.

For each test, report:

- the maximum force range applied;
- the nominal outer fibre stress range applied;
- whether the test resulted in a failure or a run-out;
- in the case of failure, the crack initiation location.

J.4.2.4 Acceptance criteria

a) All results are failures.

The process is not acceptable.

b) All results are run-outs.

The process is acceptable.

c) Both run-outs and failures occur

The mean fatigue strength shall exceed the value specified by the railway authority

J.4.3 Example of the data analysis of a fatigue strength determination by the staircase method

Table J.1 — Experimental results

σ	1	2	3	4	5	6	7	8	9	10	i	n_i	in_i	i^2n_i
230			x								2	1	2	4
220		0		x				x		0	1	2	2	2
210	0				x		0		0		0	1	0	0
200						0								
											N	4		
											A		4	
											B			6

Number of Failures (x): 4 less frequent event

Number of Run-outs (0): 6

The lowest stress range at which a failure occurs (σ_0) is 210 MPa. As failure is the less frequent event, the form of the Formula J.2 which shall be used is:

$$\sigma_m = \sigma_0 + d \cdot \left(\frac{A}{N} \pm 0,5 \right) = 210 + 10 \cdot \left(\frac{4}{4} - 0,5 \right) \text{MPa} = 215 \text{MPa} \quad (\text{J.4})$$

The standard deviation according to Formula J.3 is:

$$s = 1,62 \cdot d \cdot \left(\frac{B \cdot N - A^2}{N^2} + 0,029 \right) = 1,62 \cdot 10 \cdot \left(\frac{6 \cdot 4 - 4^2}{4^2} + 0,029 \right) \text{MPa} = 8,6 \text{MPa} \quad (\text{J.5})$$

J.4.4 Past-the-post testing method

J.4.4.1 Test pieces

Three test pieces are required. 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.

J.4.4.2 Procedure

- 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) The maximum applied stress is specified by the railway authority. The minimum stress applied shall be 10 % of the maximum stress. No failures are acceptable at an endurance of less than 5 million cycles.
- c) Cyclically load the weld using a sinusoidal waveform so that the maximum and minimum stress values are achieved. The indicated values shall both be maintained to within 2 % of the nominal value required. Continue cycling until either the test piece breaks or 5 million 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'.

J.4.4.3 Information to be reported

For each test series the following shall be reported:

- the inner and outer spans of the test rig (J.2);
- the distances from the centre line of the actuator to the loading points (J.2);
- the outer fibre stresses applied (J.4.4.2).

For each test, report:

- whether the test resulted in a failure or a run-out;
- in the case of failures, the crack initiation location.

J.4.4.4 Acceptance criterion

If any test piece breaks at less than 5 million cycles, the process shall be rejected.

Annex K (informative)

A-deviations

A-deviation: National deviation due to regulations, the alteration of which is for the time being outside the competence of the CEN/ CENELEC member.

This European Standard does not fall under any Directive of the EU.

In the relevant CEN/ CENELEC country this A-deviation is valid instead of the provisions of the European Standard until it has been removed.

Switzerland:

In addition to Clause 7.3, the following requirement has also to be fulfilled:

Application guide for railway regulation dated 2016-07-01, article 31, page number 9N, 6, clause 6:

The minimum deflection during static bending test (base 1000 mm, tension at the rail foot) at fracture shall be 10 mm. This applies for all profiles and steel grades.

Bibliography

EN ISO 7500-1:2015, *Metallic materials - Calibration and verification of static uniaxial testing machines - Part 1: Tension/compression testing machines - Calibration and verification of the force-measuring system (ISO 7500-1:2015)*

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