Railway applications — Track — Flash butt welding of rails —

Part 1: New R220, R260, R260Mn and R350HT grade rails in a fixed plant

The European Standard EN 14587-1:2007 has the status of a British Standard

ICS 25.160.10; 45.080; 93.100

British Standards

National foreword

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A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Applications ferroviaires - Voie - Soudage des rails par étincelage - Partie 1: Rails neufs de nuances R220, R260, R260Mn et R350HT dans une installation fixe

Bahnanwendungen - Oberbau - Abbrennstumpfschweißen von Schienen -Teil 1: Abbrennstumpfschweißen neuer Schienen der Güte R220, R260, R260Mn und R350HT in einem Schweißwerk

This European Standard was approved by CEN on 3 May 2007.

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Foreword

This document (EN 14587-1:2007) 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of an identical text or by endorsement, at the latest by December 2007, and conflicting national standards shall be withdrawn at the latest by December 2007.

This document is one of a series of three parts of the EN 14587 *Railway applications – Track – Flash butt welding of rails*. The list of parts is as follows:

— Part 1: New R220, R260, R260Mn and R350HT grade rails in a fixed plant

— Part 2: New R220, R260, R260Mn and R350HT grade rails by mobile welding machines at sites other than a fixed plant

— Part 3: Welding in association with crossing construction

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

Introduction

This part of EN 14587 has five main topics:

a) requirements of a welding process;

b) procedure approval for a fixed plant;

c) approval of other rail profiles or grade;

d) approval of the welding contractor;

e) weld production following approval.

This part of EN 14587 has been occasioned by a European Directive that will permit the freedom of an open European market. To enable this perception to become a reality, it is essential a standard is in place that satisfies the needs of the infrastructure owners or custodians and reflects the production capabilities of the manufacturers in technical and quality terms.

1 Scope

This European Standard specifies requirements for the approval of a welding process in a fixed plant, together with the requirements for subsequent welding production.

It applies to new Vignole railway rails R220, R260, R260Mn and R350HT grade rails of 46 kg/m and above, as contained in EN 13674-1, welded by flash butt welding in a fixed plant and intended for use on railway infrastructure.

This European Standard applies to the welding of rails into welded strings.

2 Normative references

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

EN 571-1, *Non destructive testing — Penetrant testing — Part 1: General principles*

EN 1290, *Non-destructive examination of welds — Magnetic particle examination of welds*

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

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

EN ISO 7500-1:2004, *Metallic materials — Verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Verification and calibration of the force-measuring system (ISO 7500-1:2004)*

3 Terms and definitions

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

3.1
as welded condition
rails that have been welded and trimmed only

3.2
contractor
company approved by a railway authority to provide staff and machinery to execute the production of FB weld in a fixed plant

NOTE This may include staff and machinery from within the railway authority

3.3
die burn
damage caused by localised overheating on the surface of the rail caused by poor contact between the rail and the electrode during welding

3.4
dressing
removing trimmed upset by grinding or other similar process

3.5
finished condition
welded, trimmed, dressed and profile finished

3.6
fixed plant
stationary production line for flash butt welding of rails

3.7
flat spot
process driven discontinuity showing as a small lens like shape in vertical longitudinal section, or a generally circular/elliptical shape having a localised smooth texture when viewed in a vertical transverse section

3.8
lack of bond
area of incomplete fusion between the rails in the joint. This may appear as crack like or line discontinuity at the interface either on the surface after removal of the upset or in a weld section

3.9
profile finishing
operation by which the rail head or relevant part of the rail head at the weld is returned to rail profile

NOTE The operation can be by grinding, milling, planing or any other suitable means.

3.10
purchaser
purchaser of the welds

3.11
railway authority
either the railway regulator or the owner of a railway infrastructure or the custodian with a delegated responsibility for a railway infrastructure

3.12
trimmed upset
metal remaining around the rail profile following trimming

3.13
trimming
removal of upset

3.14
upset
metal extruded around the rail profile as a result of forging

3.15
welded string
long rail comprising a number of shorter rails flashbutt welded together

3.16
welding process
part of the sequence from the selection of the rail prior to welding through to the finishing of the welded string

4 Quality management system

The contractor shall operate an independently approved and audited quality management system. A quality management system conforming to EN ISO 9001 will be deemed to satisfy the requirements. Additionally, a product quality plan shall be validated by the purchaser.

5 Requirements for the welding process

5.1 General

All welding shall be carried out on a flash butt welding machine (FBWM) using an automatic, programmed welding sequence.

5.2 Clamping force

Rails shall be secured in the FBWM by clamps of such a surface shape or contour, that when a clamping force is exerted on the rails, it shall not damage the rail in such a way that subsequent cracking in the rail in operation is generated, see 6.4.1.

5.3 Pre-heating

The fronts of the heating area shall progress uniformly perpendicularly to the running surface during the whole cycle.

There shall be no evidence of local melting on the ends of the rails during pre-heating.

5.4 Flashing

Once initiated, flashing shall be continuous.

5.5 Upsetting

Upsetting shall immediately follow flashing. Sufficient forging pressure shall be applied to ensure that voids are closed and oxides are expelled such that they are kept to a minimum at the weld interface. The weld interface shall extend into the upset.

5.6 Upset current

The upset welding current shall be maintained until the rapid forge has finished and the progressive forging commences.

5.7 Unclamping

In order to maintain the alignment, the time between completion of forging and unclamping shall be a minimum of 4 s.

5.8 Welding parameters

5.8.1 The welding machine and/or management system equipment shall be capable of displaying the following;

a) programme identification and setting details;

b) welding current;

c) upset force or pressure;

d) displacement;

e) welding time.

5.8.2 The welding parameters shall be determined during procedural trials. Once approval has been granted, the welding parameters shall not be changed, with the exception of changes concerning the environments in 5.8.4.

5.8.3 The welding parameters shall be monitored and recorded. These records shall be referenced to the appropriate welds.

5.8.4 The welding parameters shall permit the production of welds without any alteration to the program, at rail temperatures of – 10 ºC and above. Alterations of preheating parameters due to various rail temperatures are not considered as alterations to the welding program. A bending test according to 6.4.5 shall be carried out in this case.

NOTE Owing to extreme variations in seasonal temperatures, the manufacturer may request the use of alternative welding programs.

5.9 Steps across the weld

5.9.1 Any step between the rails across the weld in the trimmed but not dressed condition shall not exceed those dimensions shown in Table 1.

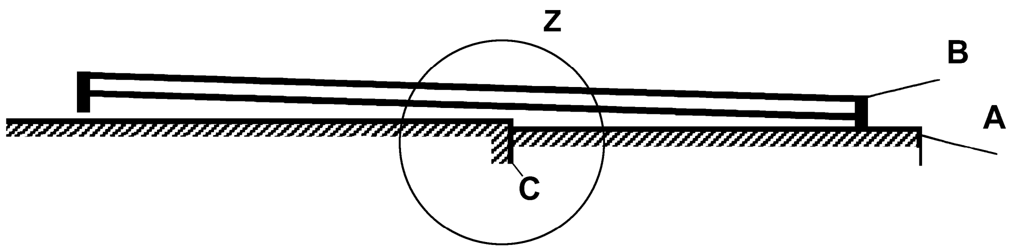
5.9.2 Checks shall be made at a position 20 mm on each side of the weld upset centreline using a 1 m nibbed straight edge and feeler shims as shown in Figure 1.

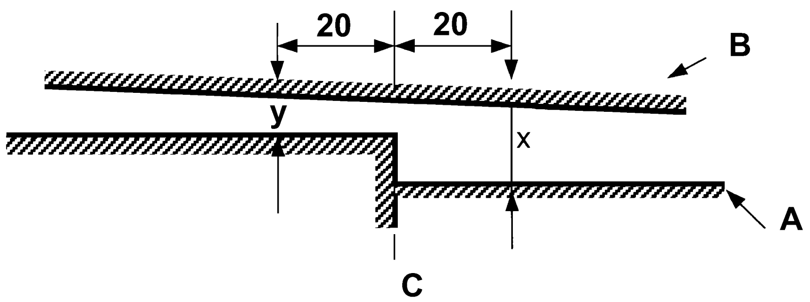
Table 1 — Maximum permitted steps

Position of step on the rail	**Maximum permitted step (in mm)**
Vertically on the longitudinal centreline of the running surface	0,5
Horizontally on the aligned face or edge 14 mm below the running surface	0,5
Horizontally on the edge of the rail foot	2,0

NOTE Where the step arises from the rail dimensions the rail foot tips may be dressed locally to achieve this requirement.

Dimensions in millimetres





Detail Z

Key

A running surface

B nibbed straight edge

C weld upset centre line

NOTE Step = |x-y| mm.

Figure 1 — Measurement of the step

5.10 Removal of excess upset

5.10.1 Excess upset shall be automatically trimmed.

5.10.2 Removal of the excess upset shall not cause any mechanical or thermal damage to the rails.

5.10.3 The surface of the trimmed area shall be free from visible cracking.

5.10.4 The weld shall be in compression during the removal of excess upset.

5.10.5 Any dressing of the weld following the removal of upset shall not cause damage to the rail or weld nor reduce either to a dimension below the original rail profile.

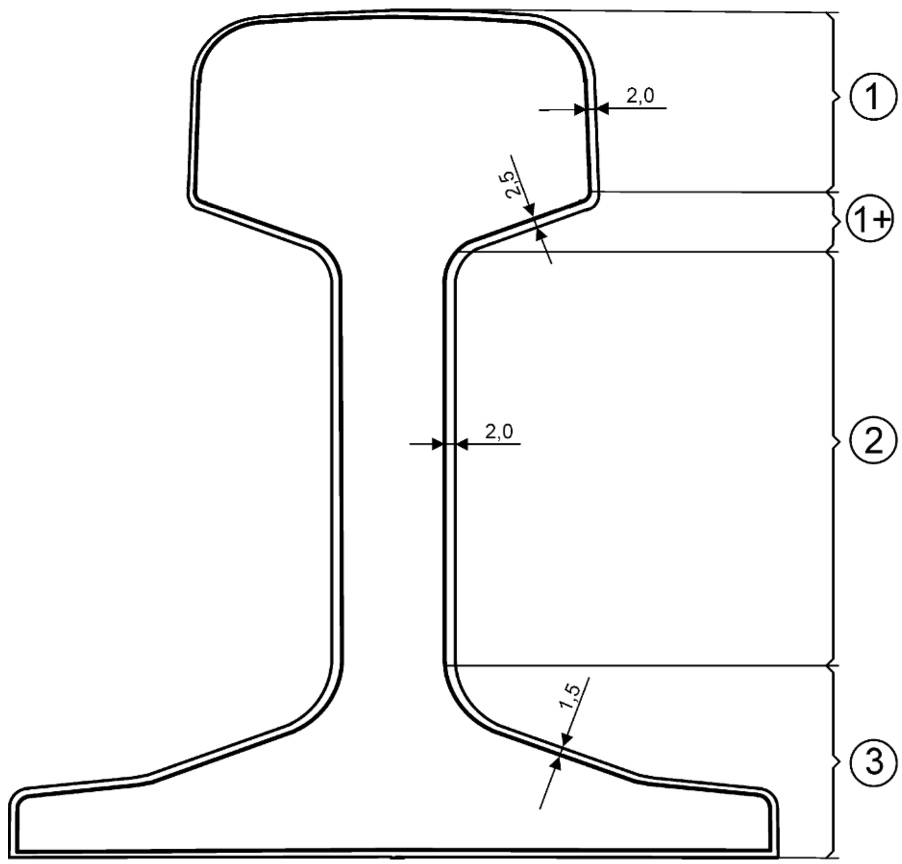
5.10.6 The maximum thickness of the trimmed upset shall be as set out in Table 2 below and shown in Figure 2.

Table 2 — Maximum permitted trimmed upset

Zone	Position of trimmed upset about the weld	Maximum permitted upset (in mm)
①	Full head profile from the lower corner on the gauge face to the lower corner on the opposite face	2
1+	The fishing surface on the underside of the head	2,5
②	The web, including the top fillet radius and extending down to the start of the bottom fillet radius	2
③	The foot, including the start of the bottom fillet radii in the web and extending to the foot tips and completely across the underside of the rail foot	1,5

Where there is a difference in the rail dimensions, the trimmed upset shall be measured in relation to the rail giving the maximum protruding surface. If the values of the trimmed upset are above the maximum values, the trimmed upset shall be dressed locally to the required values without damaging the parent rails.

Dimensions in millimetres



Key

① Zone ① – rail head

1+ Zone 1+ - on the underside of the rail head

② Zone ② – web of the rail

③ Zone ③ – foot of the rail

Figure 2 — Maximum permitted trimmed upset

5.11 Post-weld heat treatment

For the grade R260Mn, a post-weld heat treatment could be required.

For the grade R350HT, a post-weld controlled accelerated cooling could be required.

NOTE The post-weld controlled accelerated cooling is carried out after the removal of excess upset.

5.12 Rail end preparation and horizontal alignment requirements

The rail ends shall be sawn or disc cut. Areas of electrical contact on the rails and the machine shall be cleaned to bright metal to give a consistent and good electrical contact at the interface.

The rail shall not be damaged by the cleaning operation or through poor electrical contact.

Rails of the same profile shall be positioned in the welding machine such that the welding interface is central to the contact electrodes as assessed by visual or mechanical means.

Before welding, rails shall be aligned laterally to the required rail face or edge, i.e. left, or right, or to the rail centreline.

For reasons of asymmetry all rails should be welded with the brand marks on the same side throughout the welded string.

6 Procedure approval

6.1 General

Procedure approval shall be carried out by testing weld samples produced in accordance with this European Standard.

Procedure approval testing shall be carried out on the rail profile and grade specified by the purchaser, see 6.2.

All test results and weld fracture faces shall be made available for inspection.

6.2 Information to be supplied by the purchaser

The following information shall be supplied by the purchaser:

a) rail profile;

b) rail grade;

c) straightness class as in EN 13674-1;

d) running edge requirements and identification – left, right or centre alignment;

e) alignment class/classes, according to 9.9.1, Table 3;

f) type of fatigue test;

6.3 Sample preparation

For the specified rail profile and grade, five welds in the as-welded conditions (see 3.1) shall be manufactured.

Depending on the type of fatigue test specified by the purchaser, fourteen additional welds in the finished condition (see 3.5) for the staircase test method, or seven additional welds in the finished condition (see 3.5) for the past-the-post test method shall be manufactured to meet the test program.

6.4 Approval tests

6.4.1 Visual inspection

All of the welds and rails shall be inspected visually for welding, trimming, pressing, clamping or profile finishing imperfections, such as tears, cavities, cracks, damage, geometrical non-conformities, thermal damage in particular in the electrode contact areas.

6.4.2 Weld trimming

The weld upset on all the welds in the as welded condition shall be measured and shall conform to 5.10.7. In addition, there shall be no evidence in the upset of tearing, notches from the extrusion, cracks, undercut or damage to the adjacent rails.

Attention shall be given to the quality of trimming on the underside of the rail foot.

6.4.3 Weld straightness and flatness

All the welds submitted in the as welded condition shall be measured to determine the step across the weld, which shall not exceed the limits specified in 5.9.1.

All the welds submitted in the finished condition shall be measured, using the procedures in 9.9, to determine the horizontal and vertical straightness, which shall meet the requirements of the purchaser as given in 6.2 e).

6.4.4 Magnetic particle or dye penetrant inspection

Following visual inspection, all of the welds in the finished condition (see 3.5) shall undergo magnetic particle inspection in accordance with EN 1290 or dye penetrant inspection in accordance with EN 571-1.

The profile finished area and the area of the electrode contacts shall be checked. The inspected area shall be free of cracks. If any defects are revealed the welding process shall be deemed unsuitable.

6.4.5 Bend testing

Five welds in the as welded condition having met the requirements of 6.4.1 to 6.4.4 shall be subject to bend testing in accordance with Annex A.

Each bend test shall be continued until the bend test values have reached the values given in Table A.1. In case fracture does not occur, the test shall be interrupted. To ensure that fracture occurs in the welding zone, the weld shall be notched and the bend test shall be continued until the fracture takes place.

If fracture occurs about the weld line the fracture surfaces shall be inspected. The details of any weld imperfection shall be recorded in accordance with Annex B. Lack of bond shall not be permitted. Flat spots shall not be considered to be lack of bond.

If fracture occurs remote from the weld the fracture surfaces shall be checked for the presence of die burn, which if detected shall cause the process to fail approval. If fracture occurs within the rail for reasons other than die burn then another test weld specimen shall be substituted for testing.

6.4.6 Macro examination

The remaining four welds in the finished condition shall be sectioned for macro examination in accordance with D.1 and shall conform to the following requirements.

a) The visible heat affected zone shall be of a nominally symmetrical shape about the weld line and fall within the widths of 45 mm maximum and 25 mm minimum. The permissible deviation between the maximum and minimum dimensions on any weld shall not exceed 10 mm. This requirement shall apply equally to the vertical axis cuts through the full rail depth and each rail foot tip.

b) There shall be no evidence of lack of bond, inclusions, cracks or shrinkage. Imperfections that cannot be positively identified by macro examination shall be inspected by micro examination.

c) Two flat spots are accepted at the weld line provided they meet the following requirements:

   1) a maximum vertical dimension of 10 mm and a maximum thickness of 0,7 mm in the case where the flat spot appears to be a thickening of the weld line and not a lens-like appearance;

   2) a maximum vertical dimension of 4 mm and a maximum thickness of 0,7 mm in the case where a flat spot appears to be a lens;

d) There shall be no indication of embrittlement due to welding, cooling or finishing.

6.4.7 Micro examination

Following the completion of the macro examination, a micro examination shall be carried out on two of the four welds in accordance with D.2. There shall be no evidence of martensite or bainite at 100 x magnification in the visible heat affected zone.

6.4.8 Hardness testing

6.4.8.1 General

The remaining two of the four full rail depth longitudinal vertical sections taken for macro and micro examination shall be subjected to hardness testing which shall be carried out in accordance with Annex E.

6.4.8.2 Grades R220, R260 and R260Mn

For the grades R220, R260 and R260Mn, the minimum and maximum hardness values obtained shall conform to the following requirements:

a) minimum hardness shall not be less than P - 30 HV_{30}

b) maximum hardness shall not exceed P + 60 HV_{30}

where

P is the average hardness of the parent rail as measured in the hardness traverse

An isolated hardness value falling outside of the stated minima and maxima above shall be permitted when such a hardness value falls between the two adjacent values that conform to the requirements.

6.4.8.3 Grade R350HT

For the grade R350HT, the minimum and maximum hardness values obtained within 10 mm each side from the fusion line shall conform to the following requirements:

a) minimum hardness shall not be less than 325 HV_{30}

b) maximum hardness shall not exceed 410 HV_{30}

An isolated hardness value falling outside of the stated minima and maxima above shall be permitted only when found at the weld centre line.

6.4.9 Fatigue testing

The fatigue test shall be carried out in accordance with Annex C and to the requirements of the purchaser as specified in 6.2 f).

Depending on the type of fatigue test specified by the purchaser, ten welds in the finished condition (see 3.5) shall be taken for the staircase test method, or three welds in the finished condition (see 3.5) shall be taken for the past-the-post test method.

6.5 Test result report

A report, which contains the results, shall be produced. It shall include a record of the rail supplier, heat number and chemical analysis of the rail, the parameters and welding settings according to 5.8.1, photographs of the fracture faces (one per sample) of all broken test welds as well as macro and micro examination, and the rail profile grid shown in Annex B.

7 Approval of other rail profiles or grades

7.1 General

Following the initial process approval with a particular rail profile and grade, other rail profiles and the other rail grades, as contained in EN 13674-1, shall be undertaken to approval as and when required.

Similarly the other rail grades permitted by this European Standard shall be qualified for approval as and when required.

7.2 Sample preparation

For each rail profile or grade, five welds shall be submitted for approval testing in the as welded condition (see 3.1) and four in the finished condition (see 3.5).

7.3 Approval tests

All of the welds shall be subjected to approval testing and shall fulfil the requirements of 6.4, with the exception of the fatigue test (6.4.9).

7.4 Test result report

A report in accordance with 6.5 shall be produced.

8 Approval of the Welding Contractor

8.1 General

The welding contractor shall meet the approval requirements as defined in 8.2 to 8.6. The purchaser reserves the right to audit the welding contractor at any time.

8.2 Welding procedure

The welding contractor shall use welding procedures and FBWs that are approved.

8.3 Operators

The welding contractor shall maintain a system that ensures the competence of their welding operators by appropriate training and assessment.

8.4 Supervision

The welding contractor shall maintain a management and supervision system of flash butt welding that complies with the requirements of the purchaser.

8.5 Weld Inspection

The welding contractor shall maintain a system of weld inspection according to the purchaser requirements. Non conformances found during these inspections shall be recorded in the traceability system.

8.6 Equipment

Equipment shall comply with the operating manual. Inspection and calibration equipment shall comply with those requirements as agreed between the contractor and the purchaser.

9 Weld production following procedure approval

9.1 Weld production

Following procedure approval, weld production may commence on those rail profiles and grades approved.

Weld production shall be carried out in accordance with the requirements of this European Standard.

9.2 Information to be supplied by the purchaser

The following information shall be supplied by the purchaser, agreed with the manufacturer and shall be fully documented:

a) rail profile;

b) rail grade;

c) profile class as in EN 13674-1;

d) straightness class as in EN 13674-1;

e) minimum length of rail selected for welding and maximum number of short rails per string;

f) maximum length of the welded string and tolerance;

g) offloading requirements – offloading holes or blind ends;

h) welded rail end squareness;

i) running edge requirements and identification – left, right or centre alignment;

j) weld identification, see 9.5;

k) welded string identification;

l) alignment class/classes, see 9.9.1;

m) traceability system of the welds.

Welded strings shall always be sawn or disc cut and the end squareness shall be within the tolerances specified by the purchaser.

9.3 Rail end preparation and horizontal rail alignment requirements

The rail ends shall be sawn or disc cut. Areas of electrical contact on the rails and the machine shall be cleaned to bright metal to give a consistent and good electrical contact at the interface.

The rail shall not be damaged by the cleaning operation or through poor electrical contact.

Rails of the same profile shall be positioned in the welding machine such that the welding interface is central to the contact electrodes as assessed by visual or mechanical means.

Before welding, rails shall be aligned laterally to the required rail face or edge, i.e. left, or right, or to the rail centreline.

For reasons of asymmetry all rails should be welded with the brand marks on the same side throughout the welded string.

9.4 Weld parameter monitoring

Automatic monitoring and recording of the weld parameters shall be required for all welds.

The welding programme and parameters shall be as those for which approval was granted.

The records shall be analysed in accordance with the requirements of this European Standard. They shall be retained for not less than five years.

9.5 Weld identification

9.5.1 The weld shall be marked by such a means that it can be identified in-situ or otherwise for a minimum of 5 years.

9.5.2 The means of weld identification shall permit traceability to the records and information obtained at the time of production.

9.6 Visual inspections

All welds shall be visually inspected for compliance with this European Standard.

9.7 Steps across the weld

A weld with a step exceeding the maximum dimension shall be removed from the welded string. The weld shall be removed by cutting at a minimum distance of 100 mm on each side of the weld.

9.8 Finishing

9.8.1 Correction of vertical and horizontal weld alignment

The correction of the weld alignment shall be carried out by pressing. Any pressing operation shall not be carried out when the rail temperature is in the range of 200 ºC to 350 ºC due to blue brittleness.

9.8.2 Profile finishing of the rail head

9.8.2.1 The profile finishing shall not cause any thermal or mechanical damage to the weld or rail.

9.8.2.2 The contour of the rail head shall be retained during profile finishing.

9.8.2.3 Profile finishing of the rail head shall be contained in the shortest possible length, but shall in any case not exceed 400 mm on each side of the weld.

9.9 Weld straightness and flatness

9.9.1 All welds shall be checked for alignment and shall conform to the requirements of this European Standard as specified in 9.9. The straightness of the welded joint after pressing and profile finishing shall be measured, vertically and horizontally within a 1 m span.

The horizontal straightness of the head in Classes 1 and 2 shall apply to running edges only. At the request of the purchaser, the horizontal straightness in Class 3 shall apply to both potential running edges.

Any deviation from straight shall be in accordance with Table 3 at ambient temperature.

Any measurement of alignment made whilst the weld is hot, i.e. immediately following profiling, shall take into account the effect that cooling will have on the weld, such that the requirements of Table 3 are maintained.

Table 1 — Tolerances for straightness and flatness of flash-butt welds at ambient temperature

Dimensions in millimetres

Weld alignment	Class 1	Class 2	Class 3
Vertically on the running surface	+0,3 +0,1	+0,3 0	+0,4 0
Horizontally on the head at the running edge	+0,3 0	±0,3	±0,4
Horizontal step on the foot tip	1,5	2	2
Running surface flatness, measured over the length of the ground area	0,10	0,15	0,20

NOTE 1 For horizontal alignment, positive tolerances at the running edge will widen gauge.

NOTE 2 The purchaser may select from the classes above, different classes for vertical and horizontal straightness and flatness

9.9.2 Straightness and flatness across the weld shall be measured as follows:

9.9.2.1 The vertical straightness across the running surface shall be measured along the longitudinal centre line of the rail with the weld centrally between and referenced to datum points on the rail 500 mm either side of the weld.

9.9.2.2 The horizontal straightness of the weld at the running edge shall be measured on one or both faces at a point 14 mm below the running surface and referenced to datum points on the rail 500 mm either side of the weld.

9.9.2.3 The horizontal straightness of the weld across the foot shall be measured at the foot tip and referenced to datum points on the rail 500 mm either side of the weld.

9.9.2.4 The running surface flatness at the level of the weld shall be measured by means of a 1 m straight edge positioned on the ground area. The maximum gap between the straight edge and the profiled running table of the rail shall be in one of the classes in Table 3.

9.9.3 The means of measuring the weld straightness as described in 9.9.2.1, 9.9.2.2 and 9.9.2.3 above, shall be the choice of the manufacturer but in the case of any dispute a calibrated straight edge and feeler shims shall be used.

9.10 Bend testing

9.10.1 General

Test welds shall be produced or selected at a frequency of at least one per week whilst the plant is in production but regardless of production rate, and subjected to bend testing, in accordance with 9.10.3. All test welds shall be in the as welded condition (see 3.1).

All test welds shall be at ambient temperature when tested. If enhanced cooling is applied other than as part of normal production, the cooling method shall be recorded on the test data sheet.

Test welds shall either be selected from the production line or be made using short test pieces.

9.10.2 Additional bend test

In addition to the routine requirements for bend tests, the following occurrences will require a mandatory bend test:

a) immediately following rectification of a welding machine malfunction;

b) immediately following machine overhaul or work other than normal maintenance;

c) immediately following any change in the welding parameters or program;

d) immediately following any change to another approved procedure;

e) immediately commencing production when the welding machine has not been used for more than one week.

9.10.3 Bend test procedure

The bend test procedure shall be carried out in accordance with 6.4.5 and Annex A. The load need be applied only until the minimum production test load limit and minimum deflection are reached, after which the test can be terminated.

The requirements for minimum bend test load and deflection for weld production tests shall be in accordance with Table A.1.

A record shall be made and shall be retained:

- the applied load;
- the applied deflection;
- the rail profile and grade;
- the reason for the test;
- the date of welding;
- The interpretation of results according to 9.10.4.

Upon completion of the bend test, should the weld have fractured, the fracture surfaces shall be examined and weld features as described in this European Standard shall be recorded. Such defects shall be investigated in accordance with 9.10.4.

9.10.4 Interpretation of results

Upon completion of the test the results shall be interpreted as follows:

a) if the weld has not fractured at the specified minimum production test load and minimum deflection, the weld shall be deemed to have met the test;

   NOTE In this case, production may commence or continue.

b) if the weld fails to meet the specified minimum production test load or the minimum deflection value, then the weld shall be deemed to have failed and a retest shall be carried out in accordance with 9.10.5. The fracture surfaces shall be examined and if die burns or the incidence of flat spots greater than that found and recorded in accordance with 6.4.5 and 6.4.9, or any other deleterious effect present, their cause shall be investigated and their absence from retest welds verified before production continues.

9.10.5 Retesting

In the event of the bend test failing to meet the specified requirement the procedure for retesting shall be as follows if failure has occurred in a roughly vertical transverse plane through the weld or within 25 mm of the weld centre line.

Two more welds shall be tested and if both of these meet the specified requirements production may continue.

Failure of either of these welds shall result in all production welds subsequent to the previous satisfactory test being considered as suspect and subject to investigation. Welds shall be tested until two consecutive production welds are deemed to be satisfactory by meeting the specified requirements.

Corrective action not affecting procedure approval shall be carried out. Two consecutive welds shall be bend-tested with satisfactory results before production can commence or continue.

9.11 Documentation

The records, made in 9.4, 9.6, 9.9 and 9.10, shall be retained for a period of not less than five years and be made available to the purchaser as and when requested.

Annex A
(normative)

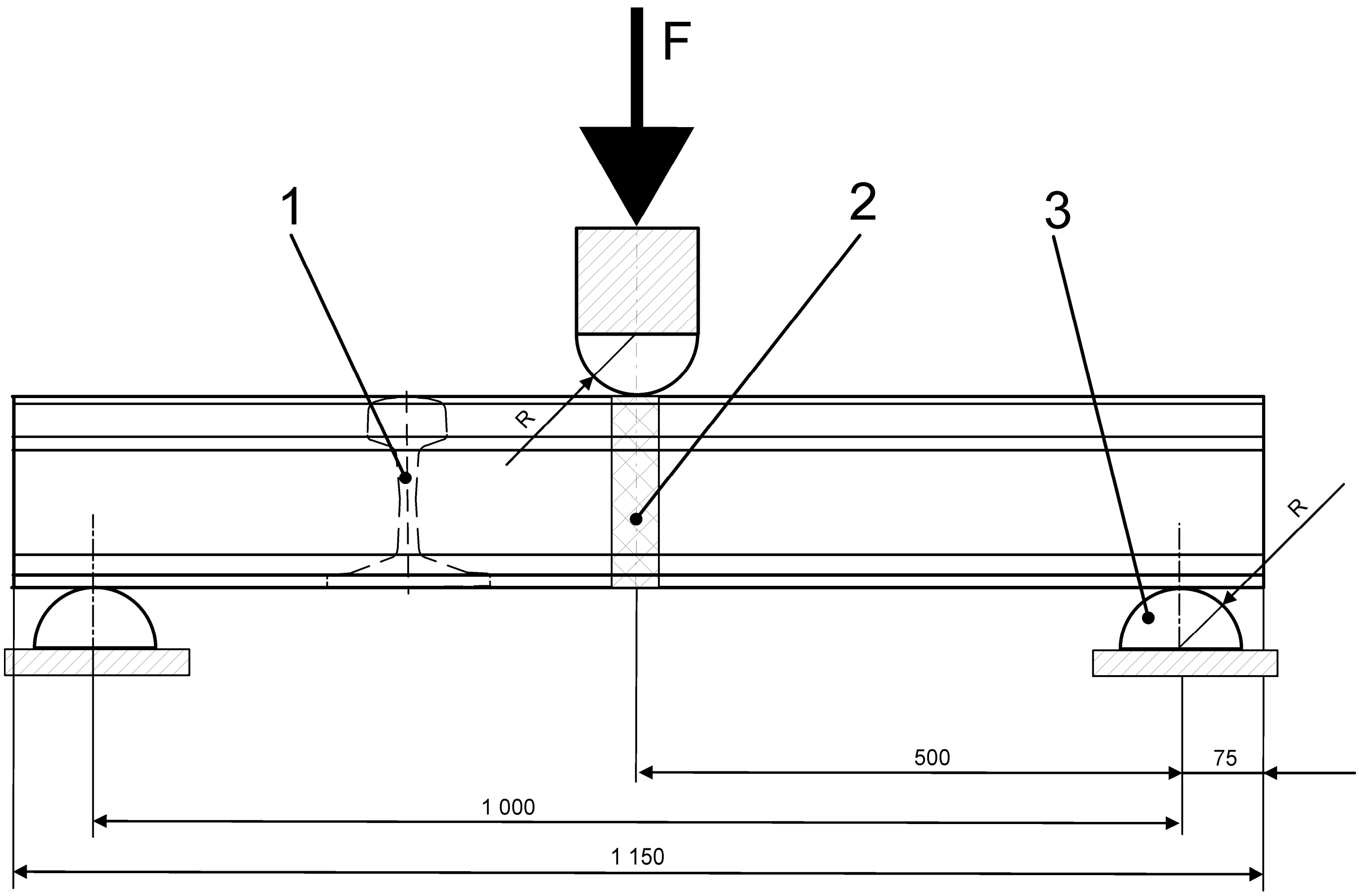
Bend test requirements

All welds shall meet the approval test requirements for the given rail profile and grade specified in Table A.1. An example of a bend test arrangement is given in Figure A.1.

Each bend test shall be continued until the bend test values have reached the values given in Table A.1. In case fracture does not occur, the test shall be interrupted. To ensure that fracture occurs in the welding zone, the weld shall be notched and the bend test shall be continued until the fracture takes place.

For production weld bend tests, the test may be stopped when the minimum force and deflection has been reached without fracture of the test specimen.

Dimensions in millimetres



Key

F force

1 elevation

2 weld

3 bearer

NOTE 1 R: 25 mm to 70 mm.

NOTE 2 Loading rate (40 to 120) kN/s.

Figure A.1 — Bend test arrangement

Table A.1 — Minimum bend test requirements

Rail Profile	Minimum bend test deflection (mm)		Minimum bend test force (kN) for approval and production	
	R220, R260 and R260Mn grade	R350HT grade	R220 grade	R260, R260Mn and R350HT grade
60E1	20	20	1 500	1 600
60E2				
56E1			1 230	1 330
55E1			1 200	1 300
54E1	25	22	1 230	1 330
54E2			1 170	1 270
54E3			1 080	1 180
52E1			1 100	1 200
50E6			1 070	1 170
50E3			1 060	1 160
49E1	30	25	950	1 050
46E1			910	1 010
46E2			930	1 030

Annex B
(normative)

Test weld fracture faces – Recording of defects

All weld fracture faces from the approval tests referred to in 6.4.5 and 6.4.9, and all weld fracture faces from production tests referred to in 9.10.1 shall be inspected and the details of any weld defects recorded.

A separate record shall be made for each weld fracture face on the rail profile grid shown in Figure B.1. The record shall show the following details relative to each defect:

a) size: x and y dimensions;

b) shape;

c) location;

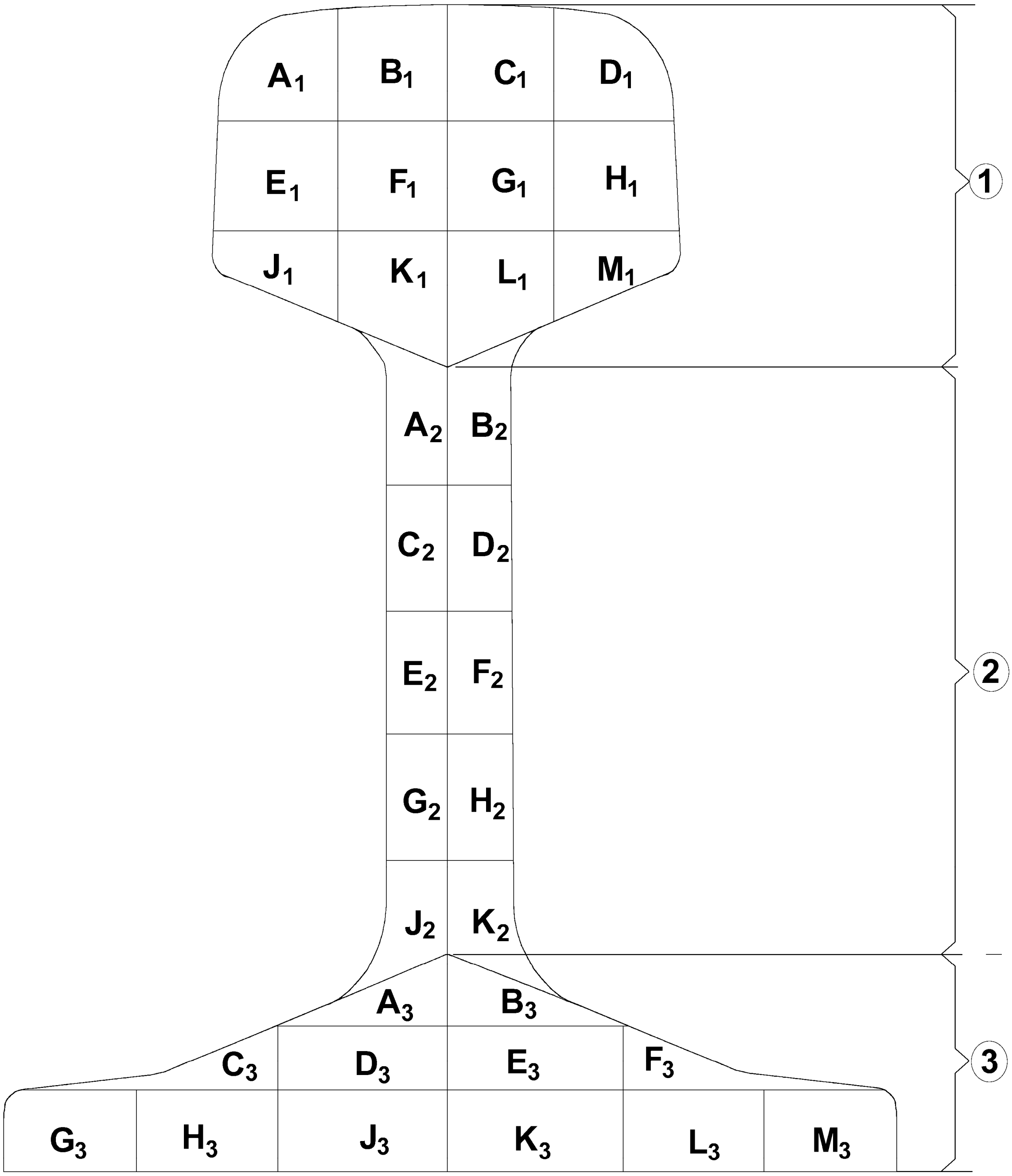
d) orientation;

e) origin of fracture;

f) type of defect.

Test weld identification and the relevant bend test or fatigue test information shall be endorsed and appended to the rail profile grid.

A weld fracture face containing no imperfections shall be similarly recorded with an entry being made on the rail profile grid to show clearly the wording "No visible imperfections".



Key

① head

② web

③ foot

Figure B.1 — Rail profile grid

Annex C
(normative)

Fatigue test method for flash butt welds

C.1 Scope

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

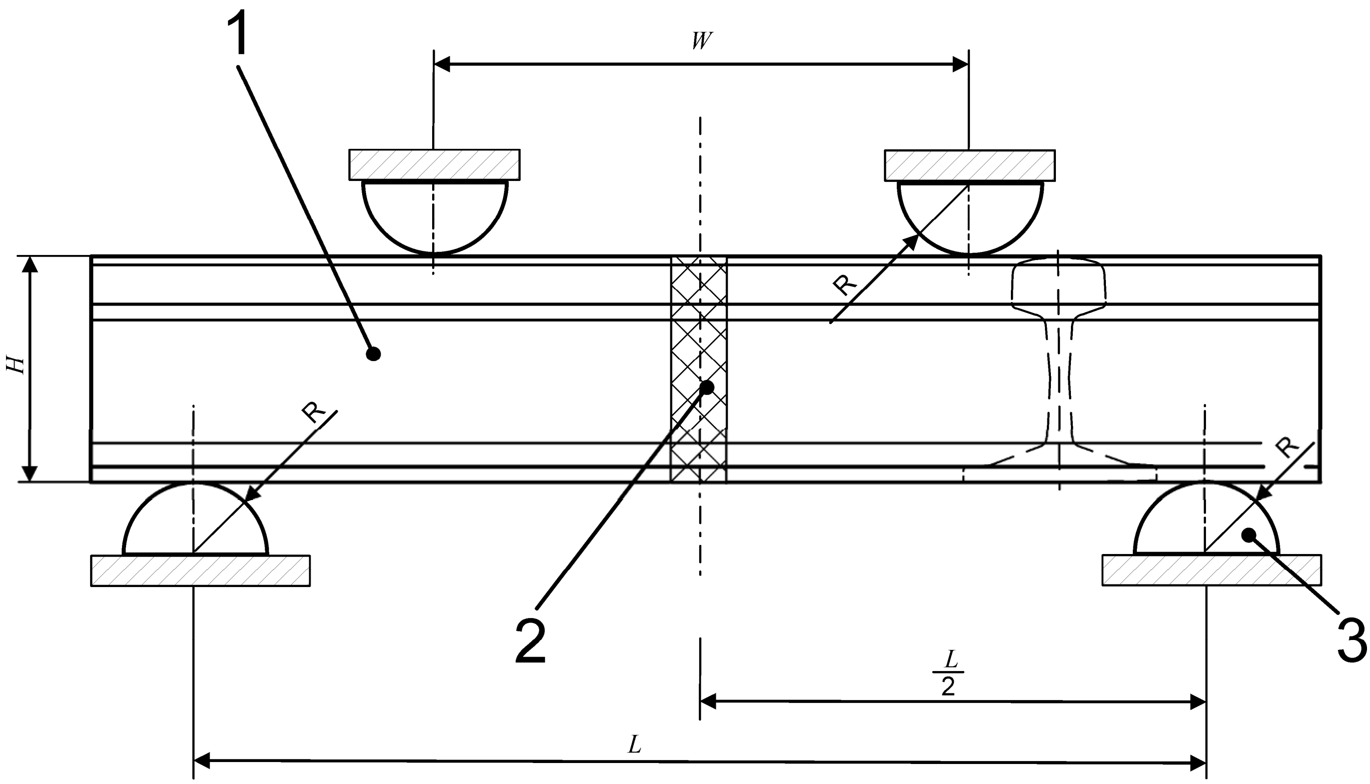
The past-the-post method (see C.4.4) is also described. Three welds shall be tested and none of them shall break below or at the defined cyclic stress level.

The relationship of the applied load to the nominal outer fibre stress is established using a length of plain rail, strain-gauged and load-cycled at the frequency of the test.

C.2 Test equipment

C.2.1 Tests shall be conducted in four point bending with the rail foot in tension.

The inner span (*W*) shall be a minimum 150 mm. 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.



Key

1 elevation

2 weld

3 bearer

NOTE 1 R: 25 mm to 70 mm

NOTE 2 Loading rate (40 to 120) kN/s

Figure C.1 — Fatigue test arrangement

C.2.2 The inner and outer spans shall be measured and recorded.

C.2.3 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.

C.2.4 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 minimised.

NOTE 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.

C.2.5 The applied force shall be measured using a fatigue rated load cell verified to EN ISO 7500-1:2004, Grade 1.0.

NOTE Depending on the outer span, a 500 kN or 1 000 kN actuator is likely to be suitable for most applications.

C.3 Calibration procedure

C.3.1 General

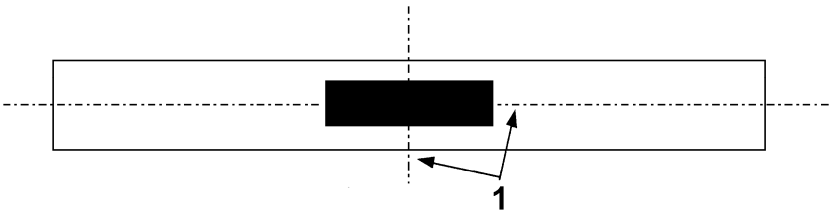
This subclause describes the determination of the relationship between the nominal outer fibre stress and the applied load.

C.3.2 Test piece

The test piece should be a section of new rail of the profile under consideration with a length exceeding that of the outer span of the test rig by no more than 100 mm.

C.3.3 Test piece preparation

Attach a strain gauge to the foot of the rail as shown in Figure C.2. Use a gauge of a nominally 350 Ω resistance and a gauge length of 6 mm. The gauge factor shall be known to an accuracy of 1 %. Attach three similar gauges to an independent block of the same steel.



Key

1 centre lines of gauge and rail to coincide

Figure C.2 — Location of gauge

NOTE For more detailed instructions on the fitment and use of strain gauges, refer to specialist manuals.

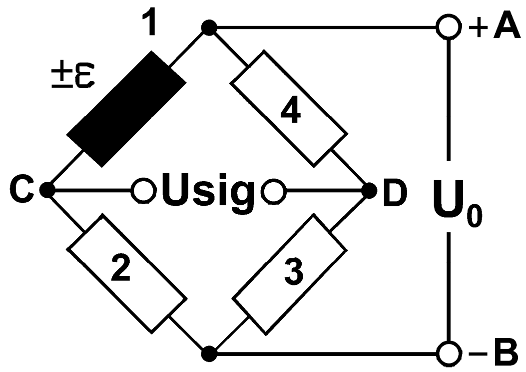
C.3.4 Instrumentation

A digital voltmeter, with peak reading circuits accurate to 1 part in 1 000 at the test frequency, shall be used.

C.3.5 Procedure

C.3.5.1 Mount the rail in the test rig with the strain gauge positioned directly beneath the actuator. The rail should be mounted so that the application of compressive loads by the actuator places the foot of the rail in tension. Position the independent block adjacent to the test piece. Wire the gauges to form a Wheatstone bridge circuit as shown schematically in Figure C.3. Apply a constant voltage of approximately 9 V DC between points A and B with A positive with respect to B.

Allow the system to stabilise for one hour before taking measurements. Measure and record the value of this voltage as U_0.



Key

1 strain gauge on the test piece

2, 3, 4, unstrained gauges on the independent block

Figure C.3 — Circuit diagram (schematic)

NOTE The wires connecting the active gauge to the remainder of the bridge are of equal length and twisted together.

C.3.5.2 Let the nominal outer fibre stress = σ. For the range of values of σ_i given in Table C.1, calculate U_{sig} using the following equation:

$$U_{sig} = \frac{\sigma_i \cdot gf \cdot U_0}{2 \cdot E} \qquad (C.1)$$

where

U_{sig} is the voltage increase between C and D when σ is increased from 0 to σ_i;

gf is the gauge factor of the strain gauge on the rail;

U_0 is the voltage applied to the bridge;

E is the Young's modulus, to be taken as 210 GPa.

C.3.5.3 Apply a cyclic force to the rail with a sinusoidal waveform and a frequency equal to that to be used for fatigue testing. For k = 1 to 8 (see Table C.1) vary the applied minimum and maximum force until the maximum and minimum vales of U_{sig} associated with the paired values of σ_i are achieved. Record the associated forces indicated by the load cell. Repeat three times, going through the full range of stresses on each occasion.

Table C.1 — Values of σ_i (MPa) for which U_{sig} is to be determined

k	σ_i (MPa)	σ_i (MPa)
1	15	150
2	17	170
3	19	190
4	21	210
5	23	230
6	25	250
7	27	270
8	29	290

C.3.5.4 Ignoring the first group of tests, tabulate the results as shown in Table C.2.

C.3.5.5 Using the data given in Table C.2, create dynamic calibration curves showing the maximum cyclic stress, and the stress range as a function of forces measured by the load cell, at the test frequency to be used.

Table C.2 — Calibration results

k	σ_i (MPa)	U_{sig} (V)	Associated force (kN)	Average force $F_{k\,min}$ (kN)	σ_i (MPa)	U_{sig} (V)	Associated force (kN)	Average force $F_{k\,max}$ (kN)	ΔF_k (kN) [a]
1	15				150				
2	17				170				
3	19				190				
4	21				210				
5	23				230				
6	25				250				
7	27				270				
8	29				290				

[a] $\Delta F_k = F_{k\,max} - F_{k\,min}$

C.4 Fatigue test method

C.4.1 General

The purchaser has the option according to 6.2 f) to select either a staircase (see C.4.2) or a past-the-post test (see C.4.4). Table C.3 defines the requirements for both types of test.

Table C.3 — Fatigue test requirements for the profile 60E1

	Staircase test method (C.4.2) Minimum requirements		Past-the-post test method (C.4.4)
Rail grade	Mean fatigue strength (MPa)	Standard deviation (MPa)	Maximum stress applied (MPa)
R220	230	27	180
R260	245	27	190
R260Mn	245	27	190
R350HT	245	27	190

C.4.2 Staircase testing method

C.4.2.1 Test pieces

Ten test pieces are required. The weld shall be positioned at the centre of the weld of the test piece to within ± 10 mm. The test piece length shall not exceed the outer test span by more than 100 mm.

C.4.2.2 Procedure

C.4.2.2.1 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.

C.4.2.2.2 Determine the maximum stress associated with the mean fatigue strength at 5 million cycles required by the purchaser.

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.

From the calibration curves created in C.3.5.5, determine the maximum force and the force range corresponding to these values of maximum stress and stress range.

C.4.2.2.3 Cyclically load the weld using a sinusoidal waveform, so that the maximum value of force and the range derived in C.4.2.2.2 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.

C.4.2.2.4 If the test piece breaks, the test result shall be recorded as a 'failure'. If it survives, it shall be recorded as a 'run-out'. The cyclic force range and nominal outer fibre stress range shall also be recorded.

C.4.2.2.5 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 force applied shall be 10 % of the maximum.

C.4.2.2.6 Where any failure is due to die-burn, the result shall be disregarded and an additional test piece made and tested.

C.4.2.2.7 Continue as above until ten test pieces have been tested.

C.4.2.3 Data analysis

C.4.2.3.1 Results are all failures or all run-outs

No data analysis is required.

C.4.2.3.2 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 following equation:

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

where

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

d = 10 MPa;

$A = \Sigma\, i \cdot n_i$ where i ranges from 0 to z;

$N = \Sigma\, n_i$ where i ranges from 0 to z.

where

n_i is the number of less frequent events at the i-th stress level above σ_0;

i is the coded stress level (i = 0 for σ_0) ;

z is the number of stress levels above σ_0 at which testing has been undertaken.

In the equation 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 following equation:

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

where

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

C.4.2.3.3 Information to be reported

For each test series the following shall be reported:

- the inner and outer spans of the test rig (C.2.2);
- the distances from the centre line of the actuator to the loading points (C.2.3);
- dynamic calibration results (C.3.5.4);
- the mean and standard deviation of the fatigue strength at 5 million cycles if calculated according to the procedure given in C.4.2.3.2.

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.

C.4.2.4 Acceptance criteria

C.4.2.4.1 All results are failures

The process is not acceptable.

C.4.2.4.2 All results are run-outs

The process is acceptable.

C.4.2.4.3 Both run-outs and failures occur

The mean fatigue strength shall exceed the value specified by the purchaser and the standard deviation shall be less than the value specified by the purchaser.

If the calculated value of $s \leq 5{,}3$ MPa, the standard deviation is small and shall be deemed acceptable. However the value given by Equation C.3 will be spurious.

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

Table C.4 — Experimental results

σ	1	2	3	4	5	6	7	8	9	10	i	n_i	$i \cdot n_i$	$i^2 \cdot n_i$
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 – anticipated

Number of run-outs (0): 6

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

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

The standard deviation according to Equation C.3 is:

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

C.4.4 Past-the-post testing method

C.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.

C.4.4.2 Procedure

C.4.4.2.1 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.

C.4.4.2.2 The maximum applied stress is shown in Table C.3. The minimum stress applied shall be 10 % of the maximum stress. No failures are acceptable at an endurance of less than 5 million cycles.

EXAMPLE If the specified stress range is 180 MPa when the ratio of the minimum to maximum applied stress (*R*) is 0,1, then the maximum stress will be 180/(1 - *R*) = 200 MPa.

From the calibration curves created in C.3.5.5, determine the maximum force and the force range corresponding to these values of maximum stress and stress range.

C.4.4.2.3 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'.

C.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 (C.2.2);

— the distances from the centre line of the actuator to the loading points (C.2.3);

— the dynamic calibration results (C.3.5.4);

— the outer fibre stresses applied (C.4.3.2.2).

For each test, report:

— whether the test resulted in a failure or a run-out;

— in the case of failures, the crack initiation location.

C.4.4.4 Acceptance criterion

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

Annex D
(normative)

Macro examination and micro examination

D.1 Macro examination

A longitudinal vertical section shall be taken centrally down the vertical axis of the full rail and extend 60 mm each side of the fusion line. Similar sections shall be taken from both sides of the foot, 10 mm inboard of the foot tips. The sections shall be polished to a suitable finish using a minimum 220 grit paper. One full depth rail sample and the associated rail foot samples from each of the four welds shall be etched to show the weld boundary lines. In case of dispute, the FRY etching method shall be used.

The etching agent shall have the following chemical composition per 10 litres:

- 1,875 kg cupric chloride ($CuCl_2$ - $2H_20$);
- 5 litres hydrochloric acid (HCl 1,18 ml - 35 %);
- 4,2 litres distilled water.

Etching at room temperature shall be for sufficient time, 30 min minimum, in order to show the boundary lines clearly when examined.

D.2 Micro examination

Microscopic examination shall be carried out on samples from the cut sections taken from the head (one sample 20 mm x 20 mm) and foot (two samples 10 mm high x 20 mm) of two of the four welds. The samples shall be etched in 4 % Nital.

Annex E
(normative)

Hardness testing

Two welds in the finished condition shall be sectioned for hardness testing. A vertical longitudinal section shall be taken down the vertical axis of the rail head and extend approximately 100 mm each side of the weld.

The variation in hardness across the heat affected zone of each of the two welds shall be measured using the Vickers hardness test in accordance with EN ISO 6507-1 and the following parameters:

a) HV 30;

b) impressions to be on a line between 3 mm and 5 mm below the running surface on the vertical longitudinal axis of the rail. Spacing shall be at 2 mm centres;

c) the hardness traverse shall extend from the weld to points on each side of the weld at least 20 mm into unaffected parent rail.

The measurements obtained shall be recorded in graphical and numerical form.

Bibliography

[1] EN ISO 9001:2000, *Quality management systems — Requirements (ISO 9001:2000)*

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