BS EN 4677-001:2012

BSI Standards Publication

# Aerospace series — Welded and brazed assemblies for aerospace construction — Joints of metallic materials by electron beam welding

Part 001: Quality of welded assemblies

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**National foreword**

This British Standard is the UK implementation of EN 4677-001:2012.

The UK participation in its preparation was entrusted to Technical Committee ACE/61, Metallic materials for aerospace purposes.

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

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English Version

# Aerospace series - Welded and brazed assemblies for aerospace construction - Joints of metallic materials by electron beam welding - Part 001: Quality of welded assemblies

Série aérospatiale - Assemblages soudés et brasés pour constructions aérospatiales - Assemblages de matériaux métalliques soudés par faisceau d'électrons - Partie 001: Qualité des assemblages soudés

Luft- und Raumfahrt - Schweiß- und Lötverbindungen für die Luft- und Raumfahrt - Verbindungen metallischer Werkstoffe mittels Elektronenstrahlschweißen - Teil 001: Qualität der Schweißverbindungen

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# Foreword

This document (EN 4677-001:2012) has been prepared by the Aerospace and Defence Industries Association of Europe - Standardization (ASD-STAN).

After enquiries and votes carried out in accordance with the rules of this Association, this Standard has received the approval of the National Associations and the Official Services of the member countries of ASD, prior to its presentation to CEN.

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of an identical text or by endorsement, at the latest by November 2012, and conflicting national standards shall be withdrawn at the latest by November 2012.

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## 1 Scope

This European Standard defines the rules to be satisfied to ensure the quality of joints of metallic materials by electron beam welding (reference number 51 according to EN ISO 4063).

It applies unreservedly to the manufacturing of new parts or for repair, these operations being under the responsibility of an approved manufacturer or supplier. The final responsibility is with the design authority

## 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 875, *Destructive tests on welds in metallic materials — Impact tests — Test specimen location, notch orientation and examination*

EN 895, *Destructive tests on welds in metallic materials — Transverse tensile test*

EN 910, *Destructive tests on welds in metallic materials — Bend tests*

EN 4632-001, *Aerospace series — Welded and brazed assemblies for aerospace constructions — Weldability and brazeability of materials — Part 001: General requirements*

EN 4632-002, *Aerospace series — Welded and brazed assemblies for aerospace constructions — Weldability and brazeability of materials — Part 002: Homogeneous assemblies aluminium and aluminium alloys*

EN 4632-003, *Aerospace series — Weldability and brazeability of materials in aerospace constructions — Part 003: Welding and brazing of homogeneous assemblies of unalloyed and low alloy steels*

EN 4632-004, Aerospace series — *Welded and brazed assemblies for aerospace constructions — Weldability and brazeability of materials — Part 004: Homogeneous assemblies highly alloyed steels*

EN 4632-005*, Aerospace series, Weldability and brazeability of materials in aerospace constructions — Homogeneous assemblies of heat resisting Ni or Co base alloys*

EN 4632-006*, Welded and brazed assemblies for aerospace constructions — Weldability and brazeability of materials — Part 006: Homogeneous assemblies titanium alloys*

EN ISO 4063, *Welding and allied processes — Nomenclature of processes and reference numbers (ISO 4063)*

EN ISO 5817, *Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections (ISO 5817*)

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

EN ISO 6947, *Welding and allied processes — Welding positions (ISO 6947)*

EN ISO 10042, *Welding — Arc-welded joints in aluminium and its alloys — Quality levels for imperfections (ISO 10042)*

EN ISO 14731, *Welding coordination — Tasks and responsibilities (ISO 14731)*

EN ISO 14744-1, *Welding — Acceptance inspection of electron beam welding machines — Part 1: Principles and acceptance conditions (ISO 14744-1)*

EN ISO 14744-2, *Welding — Acceptance inspection of electron beam welding machines — Part 2: Measurement of accelerating voltage characteristics (ISO 14744-2)*

EN ISO 14744-3, *Welding — Acceptance inspection of electron beam welding machines — Part 3: Measurement of beam current characteristics (ISO 14744-3)*

EN ISO 14744-6, *Welding — Acceptance inspection of electron beam welding machines — Part 6: Measurement of stability of spot position (ISO 14744-6)*

EN ISO 15609-3, *Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 3: Electron beam welding*

EN ISO 17659:2004, *Welding — Multilingual terms for welded joints with illustrations (ISO 17659:2002)*

ISO 857-1:1998, *Welding and allied processes — Vocabulary — Part 1: Metal welding processes*

ISO 4969, *Steel — Macroscopic examination by etching with strong mineral acids*

ISO 22826, *Destructive tests on welds in metallic materials — Hardness testing of narrow joints welded by laser and electron beam (Vickers and Knoop hardness tests)*

ISO 24394, *Welding for aerospace applications — Qualification test for welders and welding operators — Fusion welding of metallic components*

ISO/TR 25901, *Welding and related processes — Vocabulary*

# 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 857-1:1998 and EN ISO 17659:2004 and the following apply.

## 3.1 General

### 3.1.1 Electron beam welding

fusion welding process using the transformation of the kinetic energy of beam electrons into thermal energy when they strike the material

Note 1 to entry: The electrons are obtained from a cathode heated under a secondary vacuum (1 Pa to $10^{-4}$ Pa).

Note 2 to entry: The welding operation may be performed under a controlled atmosphere, generally under a primary vacuum (100 Pa to 1 Pa) or secondary vacuum.

## 3.2 Technical terms

### 3.2.1 Welding parameters

**3.2.1.1**
**run-out**
interval encompassing all geometrical irregularities of the joint plane

Note 1 to entry: This interval is measured on the detail parts, positioned in their welding setup, and is used as a reference to determine the minimum width of the weld zone.

**3.2.1.2**
**beam centering**
alignment of the beam axis on the joint plane

**3.2.1.3**
**beam deflection**
controlled movement of the beam in relation to the physical axis of the gun

**3.2.1.4**
**level distance**
difference in level (height) between two detail parts at the joint plane

**3.2.1.5**
**firing (working) distance**
distance between the impact point of the beam on detail parts and a reference surface linked to the gun or the machine (example: middle of the closest focusing coil of the detail part, electron gun base)

**3.2.1.6**
**specific welding energy**
defined by ratio between the beam power over the welding speed, multiplied by 60

$$\frac{U\ (\text{Volt}) \times I\ (\text{Ampere}) \times 60}{V\ (\text{cm/min}) \times 1000}\ (\text{in kJ/cm})$$

**3.2.1.7**
**focusing current intensity**
intensity of the current crossing the focusing coil enabling electron beam concentration on a point called the focusing point

Note 1 to entry: The intensity may be constant or modulated.

**3.2.1.8**
**beam current**
electron flow emitted by the cathode

Note 1 to entry: This current may be constant or modulated.

**3.2.1.9**
**clearance before welding *(Fit up)***
distance measured on a straight section of the joint between the surfaces to be welded

**3.2.1.10**
**slope *(or ramp)* up**
operating conditions for which the penetration depth varies incrementally

**3.2.1.11**
**focusing level**
distance between the beam impact point on the detail parts and the focusing point

Note 1 to entry: Conventionally, this distance is negative when the focusing point is within the detail parts.

**3.2.1.12**
**perveance**
ratio of the beam current over the acceleration voltage at power 3/2

$$\frac{I}{U^{\frac{3}{2}}} = c^{te}$$

**3.2.1.13**
**beam power**
product of the acceleration voltage and the beam current

**3.2.1.14**
**acceleration voltage**
difference in potential between the cathode and the anode, used to create the electric field intended to accelerate the electrons

**3.2.1.15**
**beam oscillation**
periodic movement of the beam axis in relation to the weld pool

Note 1 to entry: This oscillation is defined by the signal shape, its amplitude, frequency and direction in relation to that of welding.

**3.2.1.16**
**welding speed**
length of the weld on beam impact side produced per time unit

### 3.2.2 Other technical terms

**3.2.2.1**
**welding campaign**
series of welding operations on identical parts, executed on the same machine, without any changes of welding parameters, without performing other welds on the machine, without interrupting manufacturing for more than a week

**3.2.2.2**
**welding cycle**
succession of different welding phases performed by the welding machine to make a weld

**3.2.2.3**
**tacking pass**
pre-assembling of elementary detail parts using the same process as the one used for welding, consisting of making a slightly penetrating, narrow weld, continuous or discontinuous along the joint plane, with the purpose of maintaining the detail parts in position

**3.2.2.4**
**adjustment verification specimen**
a flat test specimen of the same material, subjected to the same heat treatments as the detail parts, on which a melt run will be made in the middle using the parameters identical to those used for parts, and for which the relationship between the micrographic shape of the cross section cut of the bead and that obtained on test specimens or real parts has been previously defined

**3.2.2.5**
**structural state**
metal crystalline structural state

**3.2.2.6**
**manufacturing**
performance of welding operations on new parts or repairs to existing assemblies (or products)

**3.2.2.7**
**stabilized manufacturing**
manufacturing for which the reliability can be established without quality issue over several welding campaigns, of which the number is previously defined by the appropriate department of the design authority

**3.2.2.8**
**smoothing pass or cosmetic pass**
remelted surface of the welded zone

**3.2.2.9**
**batch of parts**
set of parts with the same reference from:

— the same welding campaign;

— the same heat treatment batch;

— traced material (processing, chemical analysis, …).

**3.2.2.10**
**material/Parent material**
material or metal used to make the detail parts

**3.2.2.11**
**filler material**
additional alloy or metal used to make the weld of an assembly or a deposit

**3.2.2.12**
**tooling**
equipment required to hold and position parts before and during welding

**3.2.2.13**
**beam stopper (catcher)**
part intended to intercept the residual energy crossing the beam in the case of a through weld

Note 1 to entry: The material making up the beam catcher should be of a same grade or a grade compatible with the required quality of the assembly.

**3.2.2.14**
**detail part**
individual element to be assembled with other elements to make up a complete part

**3.2.2.15**
**part - product**
assembly comprising several assembled detail parts

**3.2.2.16**
**tack welding**
pre-assembly of detail parts by welding consisting of a set of tacks along the joint plane, intended to hold the detail parts in position

**3.2.2.17**
**pre-heating**
heating of detail parts before welding without fusion

Note 1 to entry: This operation will be carried out with an unfocused beam or any other process not involving magnetism.

**3.2.2.18**
**through weld**
case where the beam crosses all the thickness of parts to weld and case where the beam propagates through all the parts to be welded

**3.2.2.19**
**blind weld**
case where the beam only crosses part of the thickness of the parts to weld and case where the beam only partially propagates through the thickness of the parts to be welded

**3.2.2.20**
**qualification test specimen**
welded assembly to be used for inspection purposes

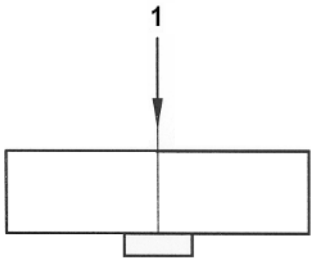
**3.2.2.21**
**manufacturing test specimen**
– test specimen representing manufactured parts to be welded under the same conditions as those parts;
– test specimen made from the same material grade, in the same condition, with the same dimensions as the manufactured part.

Note 1 to entry: Manufacturing test specimens may be actual parts.

**3.2.2.22**
**pool support**
element positioned on detail parts to prevent the fused metal from overflowing

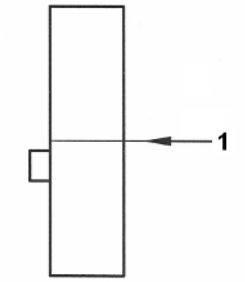
Note 1 to entry: The material making up the pool support shall be of the same base alloy as the detail parts, to prevent any weld contamination.

Note 2 to entry: The pool support may be positioned as illustrated in Figures 1 to 3:



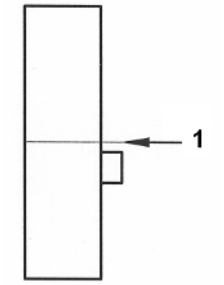

**Keys**
1 E.B.

**Figure 1 — Back support**




**Keys**
1 E.B.

**Figure 2 — Back-side support**




**Keys**
1 E.B.

**Figure 3 — Front-side support**

**3.2.2.23**
**witness lines**
alignment lines on both sides (upper and root) of the detail parts to ensure good location and the avoidance of lack of fusion

**3.2.2.24**
**post-weld heat-treatment**
treatment intended to provide the parent material and the weld zone with the requisite conditions and properties

## 3.3 General terms

**3.3.1**
**manufacturer or subcontractor**
organisation who assembles, or manufactures and assembles the elements or subassemblies into assemblies

**3.3.2**
**supplier**
individual or company holding a contract or order that it has accepted, binding it to the customer to perform the services defined therein

**3.3.3**
**customer**
individual or company placing a contract or order and who may or may not be the design authority

**3.3.4**
**operator**
person who performs the welding operations using a mechanised or automated process

**3.3.5**
**qualification**
action recognizing that a welder, product, etc. is capable of fulfilling the role for which he/it is intended

**3.3.6**
**repair**
act consisting in making acceptable a part that was felt to be beyond the acceptance criteria after its normal manufacturing and inspection cycle

Note 1 to entry: Bringing into conformity of a part which had been damaged during operation

**3.3.7**
**setter**
person responsible for fully programming the machine, the beam analysis and finalization of welding procedure specification parameters and, if necessary, performing welding operations by a mechanized or automated process

**3.3.8**
**repairer**
supplier in the specific field of repairs

**3.3.9**
**competent department**
specialist department with specific duties within a company, such as:

— design office,

— quality department,

— laboratory,

— methods office

**3.3.10**
**official supervisory body**
governmental authorities or approved organisations responsible for ensuring equipment conformity with the definition file

**3.3.11**
**design authority**
the organisation responsible for the design of the welded assembly and for defining the performance and inspection requirements

**3.3.12**
**welding coordinator**
See EN ISO 14731:2006

**3.4.1**
**Flat position PA**
horizontal welding, with beam axis vertical

**3.4.1.1**
**Horizontal-vertical position PB**
horizontal welding

**3.4.1.2**
**Horizontal position PC**
horizontal welding, welding axis horizontal

**3.4.1.3**
**Horizontal overhead position PD**
horizontal welding, overhead

**3.4.1.4**
**Overhead position PE**
horizontal welding, overhead, welding axis vertical

**3.4.1.5**
**Vertical up position PF**
welding up

**3.4.1.6**
**Vertical down position PG**
welding down

# 4 Weldability

## 4.1 Notion of weldability

a metallic material is considered to be weldable to a given degree, by a given process or for a given type of application when, provided that the corresponding precautions are taken, it lends itself to the production of a weld which, through its characteristics and the consequences of its presence, meets the required properties chosen as the basis for the judgement

## 4.2 Degrees of weldability

the weldability of materials is assessed according to the following four degrees:

— degree 1: material with **very good** weldability, requiring no particular precautions. Preferred.

— degree 2: material with **good** weldability but likely to require special welding precautions (for example, preheating, low feedrate).

— degree 3: material with **poor** weldability, requiring specific development for each type of part and likely to lead to manufacturing problems. Inadvisable.

— degree 4: material with **very poor** weldability. To be avoided.

# 5 Symbols and acronyms

| | |
|---|---|
| $e$ | Thickness of the thinnest part of the assembly |
| $E$ | Total thickness of 2 sheets |
| $I$ | Beam current |
| $T$ | Tempering, structural hardening, ageing |
| $U$ | Acceleration voltage |
| $V$ | Welding speed |
| E.B. | Electron beam |
| TIG | Tungsten inert gas |

# 6 General requirements

## 6.1 Weld classification

### 6.1.1 Manufacturing new parts

The design authority, at the time of part design, shall allocate a weld class to each assembly: 1, 2 or 3 according to a decremental functional severity order.

The requirements are listed in Table 1. A higher severity weld class may be allocated to meet specific problems such as manufacturing complexity or interpretation of inspection operations, etc.

**Table 1 — Weld class allocation requirements**

| Part with function | Assembly weld rupture | |
|---|---|---|
| | can affect normal operation of the part | without significant consequences |
| Vital | 1 | 2 |
| Other | 2 | 3 |

A given part may have several different weld classes.

Each weld class is associated with all of the following conditions:

— implementation before manufacturing;

— follow up during manufacturing;

— inspection on welded assembly;

— acceptance criteria.

The design authority shall insure that inspection requirements are adequate to demonstrate compliance with the design requirements.

### 6.1.2 Repair

The repairer shall comply with the requirements of the design authority.

## 6.2 Welding machines

The machines used for welding shall comply with EN ISO 14744-1. In particular, machines shall have undergone specific qualification tests for use in the aerospace industry when they were acquired or renovated.

NOTE Standard in preparation on electron beam welding machine – qualification specifications.

## 6.3 Operators and setters

### 6.3.1 Training

#### 6.3.1.1 Operator training

For any manufacturing or repair operation, the electron beam-welding operator shall have followed a training course given by the competent department of the manufacturer (part manufacturer), or an external training organization, with regard to:

— technical training on the process;

— operation of the machine used (electrical power supply, replacement of the machine electron emitter system, etc.);

— safety related to this machine and the welding operation;

— equipment, instruments and tooling required for correct operation of the machine, and performance of the welding operation;

— display and verification of welding procedures;

— positioning of the focal point in relation to the part surface;

— alignment check of the beam in relation to the joint plane;

— appearance and geometrical check of welded assemblies.

The operator shall weld beads and/or melt runs on standard parts and/or test specimens and/or manufacturing test specimens according to the validated welding procedure specification corresponding to his training.

#### 6.3.1.2 Setter training

For any manufacturing or repair operation, the electron beam welding setter shall have followed the operator training course, as well as a theoretical and technical training course given by the competent department of the manufacturer (part manufacturer), and/or an external training organization.

The training concerns:

— complete programming of the machine;

— analysis of beam quality (EN ISO 14744-2, EN ISO 14744-3 and EN ISO 14744-6);

— optimisation of welding parameters and preparation of welding procedure specification etc.

The setter shall prepare a welding procedure specification in order to validate his training.

### 6.3.2 Qualification

#### 6.3.2.1 Operator qualification

See Table 2.

**Table 2 — Operator qualification requirements**

| Test | Requirement |
|---|---|
| Near vision | Visual acuity (eyesight) shall be examined for near vision. Welder and Welding operators shall have vision acuity of 20/30 or better in each eye, and shall be able to read the Jaeger No. 2 eye chart at 400 mm or to pass an equivalent test as specified by an optometrist. Corrective vision may be used to fulfil eye test requirements. |
| Colour perception | Be capable of distinguishing and differentiating colours used in the process involved. Where it is not possible to devise a suitable test, Ishihara test may be used. |

Operator qualification shall comprise technical training on the process and production of a manufacturing test specimen, according to a given welding procedure specification and have correctly produced at least one welded part.

Production of the manufacturing test specimen according to a given parameter welding procedure specification shall be renewed each time the operator has not welded for more than six months.

Technical training on the process shall be repeated at least once every two years according to ISO 24394.

Operator qualification shall be confirmed by periodic inspection of production parts to demonstrate compliance with inspection requirements.

Operator qualification shall be awarded by the competent department of the manufacturer, who will justify the training given and the results from test specimen manufacturing.

The manufacturer shall verify the qualification of the operator, in accordance with the requirements of this standard or an equivalent standard acceptable to the design authority. Documented records shall be maintained.

In cases where incidences of non-compliance may be attributed to operator deficiencies, then the qualification procedure shall be reviewed and enhanced as necessary.

Furthermore, operators shall pass the following tests:

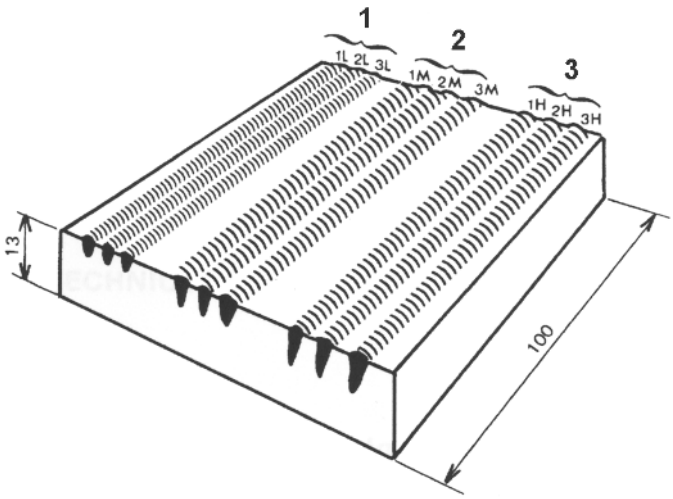
— replacement of the machine electron emitter system and verification of perveance;

— control of focusing for an intensity, a voltage and a given distance;

— adjustment of the machine to obtain a circular and homogenous beam impact for all focusing settings;

— either execute 9 melt runs on materials chosen by the welding coordinator (see Figure 4) or execute test piece according to ISO 24394.

Dimensions in millimetres




**Key**

1 Low power
2 Medium power
3 High power

**Figure 4**

— melt run sequence: 1st melt run 1L 1M 1H
2nd melt run 2L 2M 2H
3rd melt run 3L 3M 3H

— adjustment of the atmospheric pressure and cooling of the part between each melt run;

— results required (see Table 3).

**Table 3 — Definition of the weld following to minimum ratio value**

| Weld | Penetration<br>mm | Minimum ration value<br>(penetration/mid-penetration width) |
|---|---|---|
| L | Defined by the welding coordinator | Defined by the welding coordinator |
| M | Defined by the welding coordinator | Defined by the welding coordinator |
| H | Defined by the welding coordinator | Defined by the welding coordinator |

These operator qualification tests shall be repeated every two years according to ISO 24394 and each time the operator has not welded for six months.

#### 6.3.2.2 Setter qualification

The procedure defined during training (see 5.3.1.2) shall involve the production of welded parts by the setter and assessed as being in compliance by the competent department.

Setter qualification shall be awarded by the competent department of the manufacturer who shall justify the training course followed.

If the setter performs production operations, he shall be qualified according to 6.3.2.1.

This qualification shall be officially recorded in an internal document.

### 6.4 Responsibility

Weld classification is the responsibility of the competent department of the design authority.

Machine acceptance and qualification is the responsibility of the manufacturer who shall, in addition, designate a competent person responsible for the application of this standard

The satisfactory performance, as well as the choice of inspection operations that are not imposed by this standard are the responsibility of the competent departments of the manufacturer and the supplier or repairer.

If the requirements stipulated in this standard are not observed, the competent departments of the manufacturer, design authority or repairer may request the cessation of manufacture

The final decision regarding the compliance of welded parts and the acceptability of non-conforming parts shall rest with competent departments within the "design authority".

## 7 Technical requirements for manufacturing new parts

### 7.1 Materials

Definition of weldability degree is given in EN 4632-001, EN 4632-002, EN 4632-003, EN 4632-004, EN 4632-005 and 4632-006.

### 7.2 Preparation of welding procedure specification

#### 7.2.1 Generality of procedure

All welding parameters should be determined (or confirmed), qualified and documented in a welding procedure specification, at the following stages:

— before launching the manufacture of new products on a given machine;

— after any work on the welding machine likely to affect the operating parameters, for example:
  — machine location change;
  — modification of the electrical circuit of the machine;
  — power supply source change;
  — modification of part carrier or gun position and movement tooling;
  — modification of control, adjustment and viewing desks and cabinets, powering, positioning, welding, safety, pumping;

In all these cases, qualification of welding operation parameters shall be repeated if the qualification tests of the machine, according to EN ISO 14744 provide different results, from those obtained before the machine was modified:

— before any modification to the manufacturing procedure of a product already being manufactured, and likely to affect the assembly quality, for example:
  — surface preparation;
  — weld thickness;
  — heat treatment before and after welding;
— transfer to a higher severity class;
— unacceptable increase in welded part/ assembly in 6.3 and 6.4.

However, manufacturing launch of a new product does not require modification of operating parameters if assemblies are already being manufactured that already satisfy all of the following conditions:

— same or higher severity class;
— same material in the same structural state;
— identical geometry of the connection zone, penetration zone (through or blind), heat-affected zone;
— same tooling.

Qualification is decided by the manufacturer or the supplier.

The competent department of the supplier may decide to undertake a qualification operation at any time.

#### 7.2.2 Welding procedure specification

A fully documented welding procedure specification shall be prepared in accordance with the requirements of EN ISO 15609-3, by the welding coordinator or other competent person employed by the manufacturer, who shall have similar knowledge, and is qualified by the responsible design authority or recognized examining body.

An equivalent welding procedure specification format, acceptable to the design authority may be used.

The welding procedure specification shall include a reference, the date of qualification and be endorsed by the welding coordinator or a competent person, employed by the manufacturer.

The procedure shall detail all the information necessary to undertake the welding operations and may include but not be limited to:

  — Reference to the welded assembly, weld class, part number and title;
  — Manufacturer;
  — Equipment used, including welding machine identification;
  — Parent material:
    — Designation, form (cast, forged, rolled etc), condition (heat treatment and /or temper);
    — Dimensions.

- Filler materials:
  - Designation, dimensions, feeding system (if any).
- Joint design: Drawing showing joint design / configuration, dimensions and tolerances, including surface finish;
- Clearance (fit-up) on parts before welding;
- Joint preparation: Cleaning, degreasing etc.;
- Jigs, fixtures and tooling: Including that used for tacking;
- Welding position;
- Nature, dimensions and position of the beam stopper (catcher);
- Back and front support (if any);
- Demagnetism procedure (where applicable);
- Welding technique: welding position, drawing detailing all welding passes included tacking procedure and cosmetic passes (where applicable);
- Welding parameters and tolerances: Electrical, mechanical (travel direction and speed, ramp details etc, working distance, gun and chamber pressures etc;
- Definition of the parameter verification specimen and the macro-graphic shape of the bead to be observed;
- Pre- and post-weld heat-treatment, where applicable (may be undertaken using the electron beam)
- Inspection and quality requirements:
  - requirement to record actual weld parameters
  - details of alignment lines (witness lines) on both sides (face and root) of the detail parts to ensure good location and the avoidance of lack of fusion (where applicable)

A template for a weld procedure is included within EN ISO 15609-3 with additional information:

- Machine program reference
- Specific energy of welding kJ/cm
- Type and geometry of the anode
- Geometry of the cathode
- Nature and positioning of beam catcher
- References of fixture
- Clearance before welding: level difference, run-out

The welding procedure specification shall include a reference, the date of qualification and be endorsed by the welding coordinator or a competent person, employed by the manufacturer, who shall have similar knowledge, and is qualified by the responsible design authority or recognized examining body.

### 7.2.3 Qualification tests

#### 7.2.3.1 Requirements

Tests and inspection operations to carry out for welding parameter qualification depend on the weld class.

The minimum requirements are given in Table 4.

The competent department of the design authority and / or manufacturer and/ or supplier may require further tests in addition to those listed in Table 4.

The competent department of the design authority and / or manufacturer and/ or supplier shall determine the location and nature of destructive test specimens, in order to characterise the strength of the welded assembly.

#### 7.2.3.2 Test methods

##### 7.2.3.2.1 Test specimens

Qualification tests and optimisation shall be undertaken on test specimens that are fully representative of the actual parts, in respect of material composition, condition and prior treatments and with a geometry in the assembly zone that simulates the actual parts. The use of actual parts and tooling is recommended where feasible.

If manufacturing incorporates specific features (for example, difficult access), it is necessary to take them into account so that the test performance conditions are as similar as possible to the effective welding conditions.

Use of real parts and manufacturing tooling is recommended.

**Table 4 — Specimen tests and inspections**

| Specimen condition after welding in relation to heat treatment | Weld class | 1 | | 2 | | | 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Degree of weldability | 1,2 | 3 | 1,2 | 3 | 4 | 1,2 | 3 | 4 |
| | Number of specimens to weld | 2 | 4 | 1 | 2 | 4 | 1 | 2 | 4 |
| before or without heat treatment [a] | Non destructive testing of surfaces | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| | Non destructive testing of internal soundness | ■ | ■ | ■ | ■ | ■ | no | ■ | ■ |
| | Dimensional check | ■ | ■ | ■ | ■ | ■ | no | no | no |
| | Metallography on cross section [c] | ■ | ■ | ■ | ■ | ■ | no | ■ | ■ |
| | Hardness profile or mapping [d] | ■ | ■ | ■ | ■ | ■ | no | no | no |
| after heat treatment | Non destructive testing of surfaces after machining [b] | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| | Non destructive testing of internal soundness after machining [b] | ■ | ■ | ■ | ■ | ■ | no | ■ | ■ |
| | Metallography on cross section [c] | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| | Hardness profile or mapping [d] | ■ | ■ | ■ | ■ | ■ | no | no | no |
| | Mechanical characterization of the joint [e] | Mechanical characterization of the joint [e] | | | | | no | | |

■ On all specimens

[a] See 7.2.3.2.5.

[b] Machining re-work is only necessary if requested on real parts. It will be carried out under the conditions of the real parts (same thickness removed, same machining conditions).

[c] According to ISO 4969
- cross section sampled in single melt run zone: beginning, middle and end of bead;
- length section sample: slope down and overlap zone bead axis.

[d] According to ISO 22826

[e] Test conditions if required, reference standards:
- weld cross traction according to EN 895;
- bending according to EN 910;
- resilience according to EN 875;
- fatigue, stress corrosion, etc.

#### 7.2.3.2.2 Surface preparation

Prior machining methods shall be defined and validated, including reproducibility where applicable. A surface roughness finish may be defined.

Fusion faces and the adjacent surfaces shall be free from oxide (including anodic films), oil, grease, paint, moisture, coatings or any other substances which might affect the quality of the weld or impede the progress of welding. A maximum time delay between pre-cleaning and welding may be imposed in the welding procedure specification, where applicable.

The surface preparation procedure shall be included in the welding procedure specification.

#### 7.2.3.2.3 Welding

Test specimens shall be numbered chronologically in the sequence of welding. All operating parameters defined by the applicable welding procedure specification shall be transcribed. The records will be used as a reference during subsequent studies and/or audits. Magnetic remanence of detail parts and tooling shall not exceed 160 $A.m^{-1}$ ($2.10^{-4}$ Tesla), particularly in the direction of welding.

#### 7.2.3.2.4 Machining after welding

The machining conditions shall be identical to those used during production with regard to:

— the machining method;

— the surface state obtained (roughness).

#### 7.2.3.2.5 Heat treatment after welding

If heat treatment is carried out immediately after welding, the inspection operations before heat treatment scheduled in Tables 4 and 7 will be replaced by:

— non-destructive testing of surfaces and internal soundness after heat treatment;

— dimensional check after heat treatment.

#### 7.2.3.2.6 NDT procedure

The NDT procedure should be fully documented and endorsed by a Level three practitioner in the relevant NDT technique**.**

#### 7.2.3.2.7 Non destructive testing of external surfaces

By visual inspection and other methods, as defined in the welding procedure specification (e.g. dye penetrant, magnetic particle).

Unless otherwise defined by the design authority and recorded in the applicable weld procedure, cracks are not permitted and the acceptance criteria for other flaws are as detailed in Table 5.

**Table 5 — Acceptance criteria for geometry and external imperfections of butt welds** *(1 of 2)*

Dimensions in millimetres

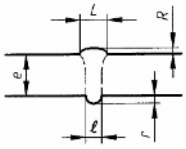
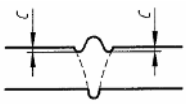
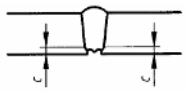
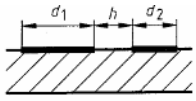
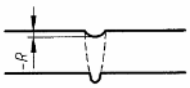
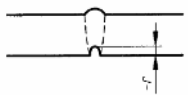
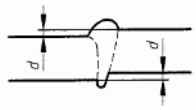
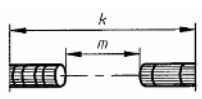
| Bead | Characteristics | Number according to EN ISO 6520-1 | Acceptance criteria |
|---|---|---|---|
| — | Crack | 100 | Not permitted |
| — | Crater crack | 104 | Not permitted |
|  | Face width: $L$ | — | Up to $e = 10 - L \leq 3 + 0{,}1\ e$ |
| | Minimum width of fused zone: $L$ min. | | $L$ min. ≥ 1 |
| | Root width: $l$ | | $l \leq 1{,}5 + 0{,}1\ e$ |
| | Excess weld metal: $R$ | 502 | $R \leq 0{,}15\ e + 0{,}1$ |
| | Excessive penetration: $r$ | 504 | $r \leq 0{,}15\ e + 0{,}1$ |
|  | Face undercut: $C$ | 5011 and 5012 | $h$ ≤ 0,05 t or 0,5 mm, whichever is the smaller<br>for $e \leq 5$: $C$ [a] ≤ 0,1 $e$<br>for $e > 5$: $C$ [a] ≤ 0,5 |
|  | Shrinkage groove: $c$ | 5013 | 0,1 $e$ or 0.5 mm, the lower of the two values is applicable |
|  | Maximum length of isolated imperfection: $f$ [b]<br>$k$: total length of weld bead | — | $f \leq 10$<br>interval between 2 imperfections: refer to « [b] »<br>$\Sigma f \leq k/20$ |
|  | Incompletely filled groove: $-R$ | 511 | 0,1 $e$ or 0.5 mm, the lower of the two values is applicable |
|  | Root concavity: $-r$ | 515 | 0,1 $e$ or 0.5 mm, the lower of the two values is applicable |
|  | Linear misalignment: $d$ | 507 | h ≤ 0,1 $t$ or 1,0 mm whichever is the smaller |
| | Lack of fusion | 401 | Not permitted |
|  | $m$: length of incomplete penetration<br>$k$: total length of weld bead | 402 | Not permitted[2] |

**Table 5 — Acceptance criteria for geometry and external imperfections of butt welds** *(2 of 2)*

Dimensions in millimetres

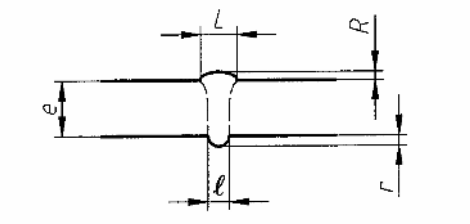
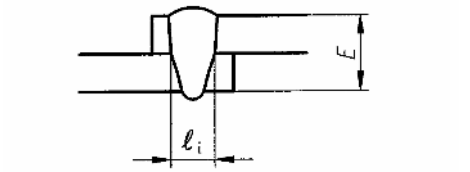
| Bead | Characteristics | Number according to EN ISO 6520-1 | Acceptance criteria |
|---|---|---|---|
| Imperfections specific to fillet welds | — | Imperfections Nos 10, 13,14, 15 and 20 according to ISO 5817 and ISO 10042. Limits for imperfection No 10 according to ISO 5817 and ISO 10042 depend on the application and shall be specified individually for each particular case | Use limits for arc welding, see ISO 5817 and ISO 10042, level B |

a (In accordance with the design authority), it is recommended that the depth of undercut shall not exceed 0,05 $e$.

b An alignment of small imperfections is considered as a continuous and isolated imperfection if the interval separating them is less than three times the length of the smallest adjacent imperfection (if $h < 3 \times d_2$, then continuous imperfection $f = d_1 + h + d_2$).

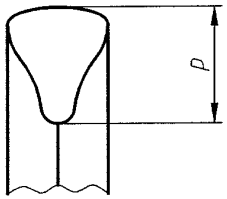
It is necessary to identify the imperfection by metallographic section inspection if there are problems interpreting the visual inspection.

**Table 6 — Density imperfection acceptance criteria** *(1 of 2)*

| Bead | Characteristics | Number according to EN ISO 6520-1 | Maximum tolerances |
|---|---|---|---|
| | Cracks | 100 | Not permitted |
|  | Butt welds [a] | 200 | $\ell_o \leq 0{,}1\ e$ for titanium, nickel alloys and steels<br>$\ell_o \leq 0{,}2\ e$ for aluminium and magnesium alloys<br>$\Sigma\ \ell_o \leq e$ over a length of $20\ e$<br>$\ell_o$: maximum length of isolated imperfection<br>$e$: thickness of the thinnest part of the assembly<br>$\Sigma\ \ell_o \leq 2 \times e$ over a length of $20 \times e$<br>with $\ell_o$: maximum length of isolated imperfection<br>and $e$: thickness of the thinnest part of the assembly |
|  | Welds by transparency in through mode [a] | — | $0{,}2 \leq \ell_o \leq 0{,}2 \times E$<br>$\Sigma\ \ell_o \leq 2 \times E$ over a length of $20 \times E$<br>with $\ell_o$: maximum length of isolated imperfection<br>and $E$: total thickness of 2 sheets |

*continued*

**Table 6 — Density imperfection acceptance criteria** *(2 of 2)*

| Bead | Characteristics | Number according to EN ISO 6520-1 | Maximum tolerances |
|---|---|---|---|
|  Take *e* as weld penetration at joint plane | Welds obtained by assembling square-edged sheets at joint plane [a] | | $0{,}2 \leq \ell_o \leq 0{,}3 \times p$<br>$\Sigma\ \ell_o \leq 2 \times p$ over a length of $20 \times p$<br>with $p \geq e$ |

[a] The slope (or ramp) down, overlap and slope (or ramp) up zones have acceptance criteria for density imperfections which are defined in particular specifications.

#### 7.2.3.2.8 Non destructive testing for internal flaws

The internal integrity of the weld bead is verified by radiography. Unless otherwise defined by the design authority and recorded in the applicable weld procedure, the acceptance criteria for internal flaws are as detailed below and in Table 6:

*In all zones, except slope (ramp) down areas:*

A cluster of isolated imperfections is considered to be a combined imperfection, if the distance between the imperfections is less than three times the length of the smallest imperfection in the cluster.

*Slope (ramp) down zones:*

A cluster of isolated imperfections is considered to be a combined imperfection, if the distance between the imperfections is less than the length of the smallest imperfection in the cluster.

#### 7.2.3.2.9 Dimensional check

This check shall be carried out after welding and before heat treatment.

The dimensional check after welding shall not reveal any dimensions outside the tolerances required by the definition.

In case of interpretation problems, different methods may be used such as moulded resin, profile projector, needle profile meter, etc.

#### 7.2.3.2.10 Metallography and hardness profile or mapping

Unless otherwise defined by the design authority and recorded in the welding procedure specification, the acceptance criteria for external and internal flaws revealed by macro- or micro-section, shall be as defined in clauses 6.2.3.2.7 and 6.2.3.2.8 and Tables 5 and 6. There shall not be any detrimental metallurgical compounds or phases present in the weld zone. The nail head imperfection shall only be accepted with the approval of a competent department of the design authority. A decrease in weld bead thickness due the presence of imperfections is not acceptable if the cumulative depth of these imperfections exceeds the maximum permitted value for an imperfection in Table 5. The minimum width of the fusion zone (see Table 5) is determined by microsection. Hardness profiles or mapping may be used to confirmed effective post-weld heat-treatment, with the absence of hard or soft zones.

#### 7.2.3.2.11 Mechanical characterisation of joint

The results of tests (for example: tension, fatigue, stress corrosion.) shall comply with the requirements of the design authority, as identified in the weld procedure.

#### 7.2.3.2.12 Parameter verification

Melt runs are made on flat test specimens with the welding parameters defined in 6.2.2 (same firing distance, voltage, intensity, welding speed, etc.).

The parameter verification specimen shall have a thickness so that a blind bead is obtained.

Cross sections are made across the bead and the macro-graphic shape is determined (penetration depth, width on beam input side, mid-penetration width) by tolerance values indicated on the Adjustment Data Sheet.

## 7.3 Process monitoring and inspection in manufacture

### 7.3.1 General

Manufacture shall be monitored during the production phase by the documented examination of test specimen or parameter verification specimen and welded assemblies. Welding machines shall be subject to regular, documented, routine preventative maintenance and calibration procedures, undertaken by suitably accredited organisations.

A properly justified relaxation in the inspection requirements may be possible during the production phase, with the prior agreement of the design authority.

### 7.3.2 Manufacturing data sheet

Per series of all electron beam. welds, the manufacturer or the supplier shall prepare a manufacturing data sheet indicating:

— the reference of the parameter data sheet;

— the dates of performance of the miscellaneous operations (surface preparation, heat treatment, etc.);

— the parameters used for welding;

— the results from inspection operations, tests and the records produced during manufacturing;

— the observations of the operator, if any.

This system is recommended for parts in weld class 3.

### 7.3.3 Follow up and inspection of manufacturing conditions

#### 7.3.3.1 Preparation of detail parts

The surface condition shall comply with 7.2.3.2.2, the dimensional tolerances of joints to weld shall correspond to those of the qualification test specimens.

A magnetic remanence of the parts to be welded and the tooling shall be checked before each welding operation. Remanent magnetism shall not exceed 160 $A \times m^{-1}$ ($2.10^{-4}$ Tesla).

Parts shall be handled in such a way as to maintain adequate cleanliness. The use of clean cotton gloves is recommended.

#### 7.3.3.2 Welding

##### 7.3.3.2.1 Verification before welding

Production welding shall be undertaken in accordance with the validated welding procedure specification.

It is recommended to prepare a checklist of operations to verify.

#### 7.3.3.2.2 Parameter tolerances

Production welding shall be undertaken using the parameters defined in the relevant validated welding procedure specification, although some adjustments within the following tolerances are permitted:

— acceleration voltage : ± 2 % of the qualified value;

— beam current : ± 5 % of the qualified value;

— welding speed : ± 5 % of the qualified value;

— focusing current intensity : ± 3 % of the qualified value;

— firing distance : ± 2 % of the qualified value.

If deviations in welding parameters are necessary outside of the tolerances defined above, then manufacturing shall cease and the causes established. If necessary, a revised welding procedure specification shall be defined and qualified.

#### 7.3.3.2.3 Gun maintenance

After any partial or complete disassembly of the gun for cleaning or part replacement, it is necessary to verify the gun perveance. This may be performed by determining the maximum intensity that can be obtained in diode mode for several known and previously defined acceleration voltages.

This operation shall be followed by a test on a test specimen to verify parameter.

#### 7.3.3.2.4 Part examination

If during welding the operator visually detects imperfections not conforming to the criteria defined in 7.2.3.2.6, manufacturing shall be stopped.

The reasons for the non-conformance shall be established and corrective action introduced.

### 7.3.3.3 Heat treatment

Heat treatment after welding shall be carried out within the time frame indicated on the adjustment data sheet.

## 7.3.4 Testing and inspection during manufacturing

### 7.3.4.1 Production conditions for manufacturing test specimens and parameter verification specimens

Manufacturing test specimens shall be identical to those used for qualification and ideally shall be subject to the same pre-treatment operations, at the same time, as the parts to be welded. Welding shall be carried out during the manufacturing campaign and under the same conditions as the parts to be welded.

For any manufacturing range, the welding technique shall be verified by the assessment of sample weld test pieces, at the following intervals, unless otherwise specified by the design authority:

a) at the start of the production run.

b) at the start of each shift.

c) after any adjustment to the welding parameters or repair to the welding machine.

d) at the completion of the production run if non destructive testing for internal flaws is not applied.

When visual inspection of both the face and root sides of the welded joint is possible and when the welds are subject to 100 % inspection of internal quality then, with the agreement of the design authority, a relaxation in the number of batch related weld test specimens may be considered.

The competent department of the manufacturer or the supplier may decide to carry out inspection operations and tests not previously imposed.

#### 7.3.4.2 Inspection of manufacturing test and parameter verifications specimens

The inspection operations to be undertaken on manufacturing test specimens are defined in Table 7.

**Table 7 — Inspection requirements**

| Specimen condition after welding in relation to heat treatment | Weld class | 1 | 2 | 3 |
|---|---|---|---|---|
| Before or without heat treatment | Non destructive testing of surfaces after machining | yes | visual | visual |
| | Non destructive testing of internal soundness | yes | yes | no |
| | Dimensional check | yes | yes | yes |
| | Metallography on cross section | yes | yes | no |
| After heat treatment after machining | Non destructive testing of surfaces after machining | yes | no | no |
| | Non destructive testing of internal soundness after machining | yes | yes | no |
| | Metallography on cross section | yes | yes | no |
| | Hardness profile or mapping [a] | yes | no | no |

[a] For weld classes 2 and 3, hardness profiles and mapping may be imposed, depending on the degree of assembled material weldability.

After welding before or without heat treatment, adjustment verification specimens shall be inspected visually and/ or metallography inspection, following to the weld class.

A macro-graphic inspection across the section shall be carried out in as-welded state.

#### 7.3.4.3 Requirements

Manufacturing test specimens shall comply with the inspection and quality requirements defined for the finished assembly in the relevant welding procedure specification.

The macro-graphic shape obtained on the parameter adjustment verification specimen shall be that indicated on the welding procedure specification.

### 7.3.5 Sentencing of test specimens

Manufacturing shall be stopped when one or more of the conditions indicated in 7.3 are not satisfied. Production undertaken since the last satisfactory test specimen shall be subject to a non-conformance procedure, to the satisfaction of the design authority. If to achieve acceptable weld quality deviations in welding parameters are necessary outside of the tolerances defined above, then manufacturing shall cease and the causes established. If necessary, a revised welding procedure specification shall be defined and qualified.

## 7.4 Acceptance of welded assemblies

### 7.4.1 Requirements

#### 7.4.1.1 Visual inspection

Unless otherwise defined by the design authority and recorded in the applicable weld procedure, all welded assemblies shall be subject to visual inspection to demonstrate compliance with the acceptance criteria defined in Table 5.

The root and face side of the weld bead shall have an even appearance. If the root side of the weld incorporates irregular solidified droplets, special care shall be paid to the inspection of the weld integrity (risk of formation of cavities in the fused zone).

The visual inspection of the face side of the weld bead shall also concern the overlap zone and slope (ramp) down zone (risk of weld bead settling at end of overlap).

Unless otherwise defined by the design authority and recorded in the applicable weld procedure, all welded joints of weld classes 1 and 2 shall also subjected to surface dye penetrant or magnetic particle flaw detection, as appropriate, to demonstrate compliance with the acceptance criteria defined in Table 5. This requirement may be waived for class 3 welds, with the prior agreement of the design authority.

#### 7.4.1.2 Radiographic inspection

Unless otherwise defined by the design authority and recorded in the applicable weld procedure, all welded joints of weld classes 1 and 2 shall be subject to radiographic inspection to demonstrate compliance with the acceptance criteria defined in Table 6. The requirements for class 2 and 3 welds shall be defined by the design authority and recorded in the applicable weld procedure for limiting the inspection to a delicate zone of the bead (overlap, slope down, etc.).

On request and indicated on definition documents, this inspection may be applied to class 2 and 3 welds. In this case, and for manufacturing runs of which the reliability is confirmed, the competent department of the supplier may decide to reduce the frequency of the radiographic inspection.

#### 7.4.1.3 Other internal integrity assessment tests

Other non-destructive test or inspection requirements may be required by the design authority and recorded in the applicable weld procedure.

#### 7.4.1.4 Dimensional check

See 7.2.3.2.9.

#### 7.4.1.5 Special requirements

Other characteristics for example, sealing, shall be verified by the appropriate means, if requested by the design authority.

Small mechanically-welded assemblies for which quality requirements do not allow the use of dye penetrant inspection, and if the configuration of assembled parts does not allow the use of a non destructive internal soundness inspection method, the competent department of the supplier may decide to assess the quality of a batch of welded parts by making metallographic cross sections of the first and last parts. Sampling of one part per batch for a metallographic cross section is sufficient for stabilized production runs.

#### 7.4.2 Acceptance criteria

See 7.2.3.2.9.

#### 7.4.3 Sentencing of assemblies

Welded parts shall be rejected if non-conforming with requirements, as defined within the welding procedure specification, is identified.

The decision is then:

— either recovery (see 7.4.4);

— or scrap.

#### 7.4.4 Repair of non-conforming welded joints

##### 7.4.4.1 General conditions

Repair solutions shall take into account:

— the effects on the mechanical and metallurgical characteristics of the welded assembly;

— the strength of the repaired welded joints and the mechanical and dimensional requirements of the design authority;

— repairs shall only be undertaken once without the prior agreement of the design authority;

— repairs shall be formally documented and underwritten by the design authority.

##### 7.4.4.2 Potential repair solutions

The following list of repair solutions include but are not limited to:

— acceptance as is on concession;

— mechanical re-work;

— smoothing or cosmetic pass with or without filler material;

— re-melt by electron beam or other welding process (e.g. TIG, laser).

Repaired welded joints shall be inspected for conformance to the original requirements

Inspection operations are defined by the competent department of the manufacturer, who may decide on the need to qualify the re-work parameters according to the procedure defined in Clause 7.

## 8 Technical repair requirements

The repair shall be fully documented. The repairer is bound to comply with the technical requirements of the welded assembly, as defined by the design authority. Any deviations shall be subject to a concessionary procedure, agreed by the design authority.

## 9 Special case

In the case of isolated parts or non repeated operations, for example:

— the manufacture of prototypes;

— test or development hardware;

— repair.

With the prior agreement of the design authority, the manufacturer may waive the preparation and qualification of weld parameters and / or supervision during manufacture. In these cases, enhanced inspection shall be undertaken during the acceptance of the welded parts.

Inspection requirements shall be underwritten by the design authority.

In all cases, unless otherwise agreed in advance by the design authority, welded assemblies shall comply with the requirements of 6.4.

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