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Structural use of steel and aluminium

Part 3: Recommendations for the execution of aluminium structures to BS EN 1090-3

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Summary of pages

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Foreword

Publishing information

This part of PD 6705 is published by BSI and came into effect on 31 December 2009. It was prepared by Subcommittee B/525/9, *Structural use of aluminium*. A list of organizations represented on this committee can be obtained on request to its secretary.

Relationship with other publications

This Published Document gives guidance on the use of BS EN 1090-3 for the execution of aluminium structures in the UK.

Information about this document

BS EN 1090-3 will replace BS 8118-2 after a period of coexistence. The replacement of BS 8118-2 will represent a substantial change in design practice in the UK. The purpose of this Published Document is to ensure that aluminium structures will be executed with the same level of assurance of reliability as that implicit in BS 8118-2.

The guidance given in this Published Document consists of non-contradictory complementary information (NCCI) to enable the user to apply BS EN 1090-3 in a safe and cost-effective manner, with particular reference to the following:

a) selection of options where they are defined in BS EN 1090-3;

b) alternative information where permitted in BS EN 1090-3.

Presentational conventions

The provisions in this Published Document are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is "should".

Commentary, explanation and general informative material is presented in smaller italic type, and does not constitute a normative element.

Contractual and legal considerations

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

Compliance with a Published Document cannot confer immunity from legal obligations.

1 Scope

This part of PD 6705 gives guidance on the use of BS EN 1090-3 for the execution of aluminium structures designed to BS EN 1999.

It is applicable to the same scope of application as in BS EN 1090-3, unless otherwise stated.

The specification information included in this document is applicable only when the design guidance in PD 6702-1 has been followed.

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.

BS EN 1011-4:2000, *Welding – Recommendations for welding of metallic materials – Part 4: Arc welding of aluminium and aluminium alloys*

BS EN 1011-6, *Welding – Recommendation for welding of metallic materials – Part 6: Laser beam welding*

BS EN 1011-7, *Welding – Recommendation for welding of metallic materials – Part 7: Electron beam welding*

BS EN 1090-3:2008, *Execution of steel structures and aluminium structures – Part 3: Technical requirements for aluminium structures*

BS EN 1289:1998, *Non-destructive testing of welds – Penetrant testing of welds – Acceptance levels*

BS EN 1435:1997+A2:2004, *Non-destructive testing of welds – Radiographic testing of welded joints*

BS EN 1714:1998+A2:2004, *Non-destructive testing of welds – Ultrasonic testing of welded joints*

BS EN 1999, *Eurocode 9: Design of aluminium structures*

BS EN 1999-1-1:2007, *Eurocode 9: Design of aluminium structures – Part 1-1: General structural rules*

BS EN 1999-1-3:2007, *Eurocode 9: Design of aluminium structures – Part 1-3: Structures susceptible to fatigue*

BS EN 14399-3:2005, *High-strength structural bolting assemblies for preloading – Part 3: System HR Hexagon bolt and nut assemblies*

BS EN ISO 6520-1:2007, *Welding and allied processes – Classification of geometric imperfections in metallic materials – Part 1: Fusion welding*

BS EN ISO 7093-1:2000, *Plain washers – Large series – Part 1: Product grade A*

BS EN ISO 10042:2005, *Welding – Arc-welded joints in aluminium and its alloys – Quality levels for imperfections*

BS EN ISO 13919-2:2001+A1:2004, *Welding – Electron and laser beam welded joints – Guidance on quality levels for imperfections – Part 2: Aluminium and its weldable alloys*

BS EN ISO 15612, *Specification and qualification of welding procedures for metallic materials – Qualification by adoption of a standard welding procedure*

BS EN ISO 15614-11, *Specification and qualification of welding procedures for metallic materials – Welding procedure test – Part 11: Electron and laser beam welding*

BS EN ISO 25239-3, *Friction stir welding – Aluminium – Part 3: Qualification of welding operators* [1)]

BS EN ISO 25239-4, *Friction stir welding – Aluminium – Part 4: Specification and qualification of welding procedures* [1)]

BS EN ISO 25239-5, *Friction stir welding – Aluminium – Part 5: Quality and inspection requirements* [1)]

PD 6702-1, *Structural use of aluminium – Part 1: Recommendations for the design of aluminium structures to BS EN 1999*

3 Terms and definitions

For the purposes of this part of PD 6705, the terms and definitions given in BS EN 1090-3 and PD 6702-1 apply.

4 Recommendations for the use of BS EN 1090-3

4.1 General

The recommendations in this part of PD 6705 are based on the National Annexes to BS EN 1999 and the design recommendations in PD 6702-1, which provides non-contradictory complementary information on the design rules in BS EN 1999.

Guidance is given in PD 6702-1 on the selection of execution class, which is one of the means of providing different levels of reliability of structural performance. This is achieved in BS EN 1090-3 by varying the level of assurance that the quality standards assumed in deriving the BS EN 1999 resistance data have been met in construction.

A major factor in the determination of the quality requirements is the degree of cyclic loading which the structural components need to resist. BS EN 1999-1-3 does not provide normative fatigue design data and the informative fatigue data in BS EN 1999-1-3:2007, Annex J, have not been accepted by the UK. Alternative fatigue rules are instead given in PD 6702-1. These latter rules are consistent with a set of quality levels, based on fitness for purpose, which are different from those given in BS EN 1999-1-3:2007, Annex J, and BS EN 1090-3. Furthermore, the quality levels assumed in PD 6702-1 are based on specific methods and extents of inspection unlike those given in the European Standards.

The quality levels and extents of inspection in BS EN 1090-3 are differentiated on the basis of two service categories depending on whether the structure/component is classified as "predominantly static" or "significant fatigue". There is no further definition in BS EN 1090-3 as to how these two conditions are to be differentiated in a quantitative way.

[1)] In preparation.

In order to overcome these impediments to safe use, PD 6702-1 has adapted the principle of the service category to provide a set of fully quantified service categories which are used to define in this document the extents of inspection and acceptance levels that are compatible with the recommended design rules in PD 6702-1 (see **4.2**).

For these reasons it is essential that the recommendations of this document are followed for execution when the recommendations in PD 6702-1 have been used for the design.

Additional information has been given in accordance with BS EN 1090-3:2008, Table A.1 and Table A.2, except where it relates to matters which might be dependent on a specific project.

4.2 Service category (see BS EN 1090-3:2008, 3.13)

These recommendations make use of the following quantified service category designations in increasing order of performance requirement: F12, F20, F25, F31, F40, F50, F63 (see **4.1**).

If no quantified service category is specified for a structure, component or part of a component, it should be assumed that F20 applies.

NOTE 1 The background to the quantified service category designations can be found in PD 6702-1.

*NOTE 2 The following subclauses of this document contain recommendations which are differentiated on the basis of quantified service category: **4.5.1, 4.5.2, 4.6.1, 4.6.3, 4.7.4, 4.8.1, 4.10.1.2, 4.10.2, 4.10.3, 4.10.4** and **4.10.5**.*

4.3 Execution classes (see BS EN 1090-3:2008, 3.8 and 4.1.2)

It should be noted that the execution class (EXC) provides a measure of the degree of assurance that the work has or will be carried out to the required quality. This is primarily differentiated by the extent of documented records as well as procedure and product testing. It does not define the quality requirement itself, which is dependent on the service category (see **4.2**).

*NOTE The following subclauses of this document contain additional recommendations relating to those requirements in BS EN 1090-3 which are differentiated on the basis of execution class: **4.4.1, 4.4.2, 4.7.2, 4.7.3, 4.7.5, 4.7.6, 4.8.2** and **4.10.3**.*

4.4 Specification and documentation

4.4.1 Quality documentation (see BS EN 1090-3:2008, 4.2.1 and Annex B)

It is recommended that BS EN 1090-3:2008, **4.2.1**, items a) to f) are documented for EXC2, regardless of whether this documentation has been specified.

4.4.2 Quality plan (see BS EN 1090-3:2008, 4.2.2 and Annex B)

It is recommended that a quality plan appropriate to the work and based on BS EN 1090-3:2008, Annex B, is prepared wherever EXC2, EXC3 or EXC4 is specified.

4.5 Constituent products

4.5.1 Wrought products (see BS EN 1090-3:2008, 5.3 and Table 1)

Where hollow extrusions formed by a porthole or bridge die are used to carry tension transverse to the direction of extrusion, special precautions should be taken during the extrusion process to verify that the die seam welds are structurally sound. These precautions are as follows.

a) The start, finish and intermediate billet-to-billet joint positions in each extruded length should be identified.

b) Sample sections from the extrusion should be cut out from the locations identified in item a). Where more than one cell exists in the cross-section, two adjacent sections should be cut out.

c) Alternate cells in the first cross-section should be subjected to expansion by forcing a tapered mandrel or "drift" into the cell until tearing occurs. This process should be repeated on the adjacent cells in the second section.

d) The tear fracture faces should be examined for evidence of poor bonding and low ductility of the extrusion weld.

e) If evidence of poor bonding is found, further sections should be taken from the extrusion and retested as in items c) and d) until sound lengths of extrusion are revealed.

f) Where it is practicable to conduct transverse tensile tests from samples taken from seam weld locations, the mechanical properties should be shown to conform to the relevant product standard.

g) In critical cases where a high transverse tensile utilization grade is required or where the quantified service category exceeds F20 in the transverse direction, it is recommended that the billet is subjected to non-destructive testing (NDT) to prove that it is free from internal flaws.

4.5.2 Castings (see BS EN 1090-3:2008, 5.3 and Table 3)

It is recommended that the guidance given in BS EN 1999-1-1:2007, **C.3.4.2**, is followed with the exception that the maximum diameter of pores given in BS EN 1999-1-1:2007, **C.3.4.2**(2), item b) should not be used. The maximum diameter of pores should instead conform to Table 1.

Table 1 **Maximum diameter of pores**

Quantified service category	Maximum pore size
	mm
F12	4,0
F20	3,0
F25	2,2
F31	1,5
F40	0,9
F50	0,5
F63	0,3

If castings require subsequent machining, the machined surfaces should be subject to further surface inspection prior to incorporation into the structure.

4.5.3 Welding consumables (see BS EN 1090-3:2008, 5.5)

The combination of parent material and consumable should conform to BS EN 1011-4:2000, Table B.2, unless otherwise specified. Where there is a choice of consumable type in this table, the criteria for selection should be agreed with the project specifier.

In all cases, the consumable should be of the same type used to qualify the weld procedures used for the project.

4.6 Preparation

4.6.1 Identification (see BS EN 1090-3:2008, 6.2)

Hard stamps should not be used in the following circumstances:

a) on 7000 alloy material;

b) where quantified service categories above F20 are required;

c) on thin material where denting might occur;

d) where otherwise forbidden by the specifier.

The same restrictions apply to soft or low stress stamps except that they should not be used where quantified service categories above F31 are required.

4.6.2 Holing for fasteners (see BS EN 1090-3:2008, 6.6)

Where holes are drilled in parts assembled and tightly clamped together, burrs on faying surfaces only need to be removed if the parts are subsequently separated prior to final assembly.

4.6.3 Assemblies (see BS EN 1090-3:2008, 6.9)

Complete or staged assemblies of structures should be used in the following circumstances:

a) where close dimensional tolerances are necessary in the final structure for functional reasons;

b) where the fit-up of butting pre-loaded bolted joints is critical to the ductility or fatigue performance of the joint. In the latter case, quantified service categories above F20 should be considered.

4.7 Welding

4.7.1 Welding processes (see BS EN 1090-3:2008, 7.3)

Welding may be carried out by the following processes subject to the recommendations in **4.7.2**, **4.7.3**, **4.7.4**, **4.7.5**, **4.10.3.2**, **4.10.4.2**, **4.10.5.2** and **4.10.5.3**:

a) laser beam welding;

b) electron beam welding;

c) friction stir welding.

4.7.2 Qualification of welding procedures (see BS EN 1090-3:2008, 7.4.1 and 7.5.1)

4.7.2.1 Arc welding

Qualification by means of BS EN ISO 15612 for EXC2 should only be allowed for 3*** and 5*** wrought alloys.

4.7.2.2 Laser and electron beam welding

Qualification of procedures should be in accordance with BS EN ISO 15614-11.

Procedure examination and testing should be in accordance with BS EN ISO 13919-2:2001+A1, acceptance level B.

4.7.2.3 Friction stir welding

Qualification of procedures should be in accordance with BS EN ISO 25239-4 [2)].

Eddy current and ultrasonic testing should be performed on butt weld test pieces prior to sectioning. Indications should be examined by macro-section. Cracks, lack of bond, lack of penetration and cavities should be cause for rejection. Any evidence of inadequate bond might require further investigation by transverse root and face bend testing.

NOTE Ultrasonic testing might require the use of specialist methods, such as phased array.

4.7.3 Qualification of welding operators (see BS EN 1090-3:2008, 7.4.3 and 7.5.1)

4.7.3.1 Laser beam and electron welding

The guidance given in BS EN 1011-6 for laser beam welding personnel and BS EN 1011-7 for electron beam welding personnel should be followed.

4.7.3.2 Friction stir welding

Friction stir welding operators should be qualified in accordance with BS EN 25239-3 [2)].

4.7.4 Welding co-ordination personnel (see BS EN 1090-3:2008 7.4.4, 7.5.1 and Table 7)

For EXC2 and parent metal other than 3*** and 5*** alloys, specific technical knowledge should be sought for all thicknesses.

4.7.5 Preparation and execution of welding (see BS EN 1090-3:2008, 7.5.1)

4.7.5.1 Laser beam welding

Laser beam welding should be carried out in accordance with BS EN 1011-6.

[2)] In preparation; due to be published in 2010.

4.7.5.2 Electron beam welding

Electron beam welding should be carried out in accordance with BS EN 1011-7.

4.7.5.3 Friction stir welding

Friction stir welding should be carried out in accordance with BS EN 25239-5[3)], with the exception that the scope of inspection and testing and the acceptance standards for production welds should be agreed between the contracting parties prior to fabrication (see **4.10.3**, **4.10.4** and **4.10.5**).

4.7.6 Temporary attachments (see BS EN 1090-3:2008, 7.5.5)

Welded temporary attachments should only be permitted when the designer is satisfied that the effects on strength have been allowed for.

It is recommended that welded temporary attachments are not permitted in the following conditions:

a) where the attachments are not removed and the quantified service category exceeds F20;

b) when the attachments are removed, ground flush, subjected to surface NDT and the quantified service category exceeds F31.

4.7.7 Tack welds (see BS EN 1090-3:2008, 7.5.6)

The requirements specified for EXC3 and EXC4 regarding their inclusion in the welding procedure specification should also be applied to EXC2.

4.7.8 Run-on/run-off pieces (see BS EN 1090-3:2008, 7.5.8)

Run-on/run-off pieces should be used for EXC2.

4.8 Mechanical fastening and adhesive bonding

4.8.1 Nut locking devices (see BS EN 1090-3:2008, 8.2.5 and 8.3.1)

Nut locking devices in non-pre-loaded assemblies should be used:

a) in lap joints where load reversal is expected in service;

b) in joints where a quantified service category exceeding F20 is used.

4.8.2 Nut designation markings (see BS EN 1090-3:2008, 8.2.5)

For EXC2, nuts above grade 4 should be assembled with their grade designations visible. However, this might not be necessary if only one grade of nut is being used in the project for each size of bolt and the nuts are assembled randomly (with a 50% probability that the designation is showing).

4.8.3 Oversized washers (see BS EN 1090-3:2008, 8.2.6)

Oversized washers should be used where oversized or slotted holes are specified.

[3)] In preparation; due to be published in 2010.

Oversized washers to BS EN ISO 7093-1:2000, hardness class 300, are recommended where pre-loaded bolts are used in joints where the minimum specified proof strength of the parent metal is less than 150 MPa.

*NOTE BS EN 1999-1-1:2007, **8.5.9.1**(1) specifies that the minimum specified proof strength of the parent metal is to be greater than 200 MPa for joints designed as slip-resistant joints with pre-loaded bolts.*

4.8.4 Tightening of pre-loaded connections (see BS EN 1090-3:2008, 8.3.2)

The part-turn method may be used for tightening pre-loaded Grade 8.8 bolts to BS EN 14399-3:2005 (HR type). Nuts to BS EN 14399-3:2005, Property Class 10, are recommended in the case of coated bolts, to reduce any risk of thread stripping. K_o bolt assemblies may be used, which do not need certified load/torque characteristics.

NOTE The part-turn method has been used as a standard method of tightening Grade 8.8 bolts in slip resistance joints in the UK and provides preloading forces in accordance with those given in BS EN 1090-3:2008, Table 8. Advantages of this method over the torque method are:

a) the lack of dependence on torque/load characteristics;

b) reduced risk of overstretching of the bolt;

c) achievement of higher margins in practice above the preloading forces in BS EN 1090-3:2008, Table 8.

Step 1 of the tightening procedure for the part-turn method involves tightening all nuts in the joint to a bedding torque. This might require more than one torquing cycle. The bedding torque values should be in accordance with Table 2.

Table 2 **Bedding torque values for Step 1 of the part-turn method**

Bolt diameter (d)	**Bedding torque**
mm	Nm
16	80
20	160
22	210
24	270
27	340
30	460

Step 2 of the tightening procedure involves indelibly marking all the nuts and the ends of the bolt threads at the same polar location, followed by applying rotations to the nuts relative to the bolts in accordance with Table 3.

Step 3 of the tightening procedure involves applying a further nut rotation, not less than 72 hours after Step 2, in accordance with Table 3.

Table 3 **Rotation values for Step 2 and Step 3 of the part-turn method**

Total grip thickness (t_g)[A]	Rotation	
	Step 2	Step 3
mm	°	°
$t_g \leqslant 5d$	180 (½ turn)	45 (⅛ turn)
$5d < t_g \leqslant 10d$	270 (¾ turn)	45 (⅛ turn)

[A] Includes packing and washers; d = bolt diameter.

4.8.5 Adhesive bonded joints (see BS EN 1090-3:2008, 8.6)

The correct performance of adhesive bonded joints is only obtained if the recommendations of the adhesive manufacturer are followed rigorously.

Therefore, a work procedure should be prepared, based on the manufacturer's instructions, and should include the following:

a) the full designation of the adhesive products;

b) the surface preparation of the parts;

c) the method of jigging and clamping the parts;

d) the method of preparing/mixing the adhesive products;

e) the tolerance limits on fit up;

f) the method of applying the adhesive to the parts;

g) restrictions on environment (e.g. temperature, humidity);

h) restrictions on time for the following operations;

- maximum shelf-life (storage before use);
- minimum mixing time;
- maximum time between mixing and joint closure;
- minimum clamping time;
- minimum curing time prior to application of load;

i) inspection stages (see **4.10.7**).

Where specific prior test data do not exist, a procedure test piece should be prepared and subjected to load test to qualify the procedure. A similar test may be carried out to quantify the operative carrying out the work.

4.9 Corrosion protection (see BS EN 1090-3:2008, Clause 10 and Annex F)

BS EN 1999-1-1:2007, Annex D, gives background information on the need for corrosion protection.

4.10 Inspection, testing and corrections

4.10.1 Constituent products (see BS EN 1090-3:2008, 12.2.1)

4.10.1.1 Prior to fabrication

BS EN 1090-3:2008, **12.2.1**, states that there are no requirements for specific testing of constituent products unless specified. The specification of testing should be deemed to include any testing requirements in the product standards specified by BS EN 1090-3. For example, in the case of EXC2, EXC3 or EXC 4, BS EN 1090-3:2008, **5.2**, requires an inspection certificate 3.1, which relates to specific testing.

4.10.1.2 After fabrication

Accessible surfaces of parent metal should be inspected by the penetrant method when the following conditions apply:

a) machined or ground surfaces which require a quantified service category of F50 or above;

b) hollow extrusions where a quantified service category of F25 or above is required in the direction transverse to the extrusion direction.

4.10.2 Methods of inspection (see BS EN 1090-3:2008, 12.4.2.1)

BS EN 1714:1998+A2, ultrasonic test class B, is deemed to be adequate for quantified service categories up to F31. For F40 and above, BS EN 1714:1998+A2, ultrasonic test class C, should be applied.

4.10.3 Extent of weld non-destructive inspection (see BS EN 1090-3:2008, 12.4.3.1, 12.4.3.2 and Annex L)

4.10.3.1 Arc welds

BS EN 1090-3:2008, Annex L, which is informative, should not be used for the scope of weld inspection, as it is based on informative design criteria in BS EN 1999 which have not been adopted by PD 6702-1.

To ensure compatibility with the design recommendations of PD 6702-1, the extent of NDT should be as given in Table 4 which gives the minimum recommended proportions of welded joints which should be subjected to supplementary NDT for the most common conditions. The percentages in this table should apply to the number of joints tested up to weld lengths of one metre in any joint. For joints with weld lengths exceeding one metre, the percentage should apply to the proportion of weld in every joint.

Where other conditions apply, the proportion tested may be increased (or decreased) by one or more levels in accordance with Table 5. This should be done by applying the next highest (or lowest) proportion using the following sequence of seven increasing levels of proportion: 0%, 2%, 5%, 10%, 20%, 50%, 100%.

For example, if the recommendation in the table is 20%, an increase of one level changes the recommendation to 50% and a decrease of one level to 10%.

If adjustments are made according to more than one condition in Table 5, the net number of levels should be used, after adding and/or subtracting the number of levels specified for each condition. For example, if the proportion in Table 4 is 100% and the adjustments according to Table 5 are –1, –1 and +1 level respectively, the net adjustment would be –1 level, which would result in a proportion of 50%.

For F25 and above, the minimum recommended proportions of welded joints which should be subjected to supplementary NDT for the most common conditions are given in Table 6.

The following points should be noted in relation to BS EN 1090-3:2008, **12.4.3.1** and **12.4.3.2**.

a) SC1 and SC2 are only used in these clauses in relation to Tables L.2 and L.3 in Annex L, which are not to be used [see BS EN 1090-3:2008, **12.4.3.2**(a)]. For this reason, these service categories do not require inclusion in the specification with respect to extent of inspection (see BS EN 1090-3:2008, **12.4.3.1**).

b) The range of quantified service categories (F12 to F63) encompasses the range of design performance conditions in BS EN 1999 and hence is equivalent to the range nominally covered by SC1 and SC2. For compatibility with PD 6702-1, the quantified service category should therefore be included in the specification for the extent of inspection (see BS EN 1090-3:2008, **12.4.3.1**). It should be noted that the "utilization grade" is only a factor in the determination of F12 (see PD 6702-1:2009, Table 2).

c) BS EN 1090-3:2008, Table 9, represents a minimum scope of application of the test methods, which is increased in some situations in Table 4, Table 5 and Table 6 of this document.

d) The use of BS EN 1090-3:2008, Annex J, for the designation of requirements for each weld is not recommended. The requirements for each weld do not need to be explicitly stated if F20 and EXC2 apply, which is the most common situation (see BS EN 1090-3:2008, **4.1.2**, and PD 6702-1:2009, **4.1.5.1**). Otherwise the quantified service category and execution class only need to be specified for each joint, component or part of the structure when fully defining the methods and extent of inspection (and acceptance criteria; see **4.10.5**).

4.10.3.2 Laser beam, electron beam and friction stir welds

The extent of NDT should be similar in principle to that given in Table 4, Table 5 and Table 6. However, it is recommended that this is reviewed on a project basis and agreed between the contracting parties prior to fabrication (see also **4.10.4.2**).

4.10.4 Destructive testing (see BS EN 1090-3:2008, 12.4.3.3)

4.10.4.1 Arc welding

For quantified service categories above F31, it is recommended that run-on/run-off plates on longitudinal welds are tested on a 5% basis and a macro-section taken to verify the internal quality. This should include a tack weld if these are used in the work.

4.10.4.2 Laser beam, electron beam and friction stir welding

The general principles for longitudinal welds in **4.10.4.1** should apply to these processes.

In the case of friction stir welding, more emphasis should be placed on bend testing of production run-on/run-off plates, with a reduced emphasis on ultrasonic testing, to provide assurance that bond integrity is being maintained. This principle should be applied to transverse butt welds for quantified service categories of F20 and above.

4.10.5 Acceptance criteria for welds (see BS EN 1090-3:2008, 12.4.4, Annex L and Annex M)

4.10.5.1 Arc welding

BS EN 1090-3:2008, Annex L and Annex M, should not be used for weld acceptance criteria as they are based on informative design criteria in BS EN 1999 which have not been adopted by PD 6702-1.

To ensure comparability with the design recommendations of PD 6702-1, the weld acceptance criteria should be applied in accordance with the following tables in this document, according to the method of inspection used:

a) visual inspection: Table 7 and Table 8;

b) penetrant testing: Table 9;

c) ultrasonic and optional radiographic testing: Table 10.

The following points should be noted in relation to BS EN 1090-3:2008, **12.4.4**:

1) SC1 and SC2 are only used in these clauses in relation to Tables L.4 and L.5 in Annex L, which are not to be used (see BS EN 1090-3:2008, **12.4.4.1** and **12.4.4.2**). For this reason, these service categories do not require inclusion in the specification with respect to weld acceptance criteria (see BS EN 1090-3:2008, **12.4.3.1**).

2) The acceptance criteria in Table 7, Table 8, Table 9 and Table 10 are consistent with the principles used in BS 1090-3:2008, **12.4.4**, including the referenced annexes and standards, as follows:

   i) reference is made to BS EN ISO 10042 imperfections;

   ii) some BS EN ISO 10042 imperfections have been omitted;

   iii) some BS EN ISO 10042 imperfection limits have been altered;

   iv) additional imperfections have been added.

3) The acceptance criteria in Table 7, Table 8, Table 9 and Table 10 represent the physical limits which are acceptable for performance purposes. No allowance has been made for measurement error. In cases of doubt, particularly in the assessment of a buried imperfection, the imperfection should be rejected and its true dimension verified by excavation for the purposes of calibration of the NDT measurement technique.

4.10.5.2 Laser and electron beam welding

The imperfection types to which these processes are susceptible are not dissimilar to those to which arc welding processes are prone. The size, shape and risk of occurrence might be different, according to the procedure, joint geometry and materials being welded.

For the purposes of specifying acceptance criteria, based on fitness for purpose principles, the dimensional limits in Table 7, Table 8, Table 9 and Table 10 may be used as a guide in terms of the required quantified service category.

It is recommended that the acceptance criteria are reviewed on a project basis and agreed between the contracting parties prior to fabrication.

4.10.5.3 Friction stir welding

This process does not involve fusion of the materials and is therefore not prone to some of the imperfections found in arc welding (e.g. cracks, porosity and lack of fusion).

The process is still prone to profile and geometrical discontinuities including lack of penetration. While lack of fusion does not occur, inadequate bonding might occur, which has similar characteristics in terms of its potential as a cause of loss of section and as a crack initiator. However, it is more difficult to detect ultrasonically (see **4.10.4.2**).

For the purpose of specifying and agreeing acceptance criteria, the recommendations in **4.10.5.2** apply in principle. The limits for lack of fusion may be deemed to be suitable for assessment of inadequate bonding.

NOTE For further information on imperfections and their terminology in friction stir welds, see BS 499-1, BS EN 25239-1 and BS EN 25239-5. The dimensional limits specified in BS EN 25239-5 might not be appropriate for acceptance of production welds, depending on the required service category.

4.10.6 Inspection of bolting (see BS EN 1090-3:2008, 12.5)

In pre-loaded connections, the bolt/nut assembly should be rejected if the rotation is double marked (see BS EN 1090-3:2008, **12.6**).

4.10.7 Adhesive bonding (see BS EN 1090-3:2008, 12.6)

Inspection stages should include:

a) verification of the adhesive products and their expiry dates;

b) verification of the condition of the parts prior to the application of the adhesive;

c) verification of the fit up of the joint and the extent of coverage around the joint by visual inspection.

Consideration should also be given to the use of coupon samples during production which would be load tested at specified intervals to provide assurance of quality.

4.10.8 Parent material

Penetrant dye testing in accordance with **4.10.1.2** should show the surfaces to be free of indications.

Table 4 **Minimum extent of supplementary NDT of shop welds in all alloys, except 7***, for EXC2 and quantified service category F20**

Weld type	Orientation [A]	Thickness (t) or throat (a) [B] mm	Proportion of joints tested %	
			Penetrant testing (PT)	Ultrasonic testing (UT) [C]
Butt	Transverse	$t < 8$	100	Not applicable
		$8 \leqslant t \leqslant 20$	20	50 [D]
		$t > 20$	50	100
	Longitudinal	$t < 8$	50	Not applicable
		$8 \leqslant t \leqslant 20$	5	0
		$t > 20$	10	10
Fillet	Transverse	$t \leqslant 20$	5	No requirement
		$t > 20$, $a \leqslant 10$	10	No requirement
		$t > 20$, $10 < a \leqslant 15$	20	0
		$t > 20$, $a > 15$	20	10
	Longitudinal	As per transverse fillet but reduced by 2 levels [E]		

[A] Transverse applies to all welds orientated within 60° of the longitudinal axis of members, except for connection zones where all orientations are deemed to be transverse. Connection zones are all locations within 200 mm of a main structural connection, loading point or support position.

[B] t = the maximum parent metal thickness in the joint.
a = fillet weld throat dimension (including any specified penetration).

[C] Evaluation level DAC –14 dB.

[D] 100% for single sided butt where no access to root side.

[E] See **4.10.3.1**

Table 5 **Adjustments in proportions of NDT for conditions other than those covered by Table 4 and Table 6**

Condition	Change in level [A]
Site welded joints	+1
Automatic and robotic welded joints [B]	–1
Standard proprietary products manufactured on a mass production basis [B]	–1
EXC3	+1
7*** alloys	+1
Quantified service category F12 (relative to F20)	–1
After a non-conformance with acceptance criteria in Table 9 or Table 10, applicable to all joints of similar type tested in the same production batch; to be maintained until the cause has been identified and rectified and defects eliminated	+2 (min.)

[A] See **4.10.3.1**.

[B] Not applicable to transverse butt welds of F31 and above.

Table 6 **Minimum extent of supplementary NDT of shop welds in all alloys, except 7***, for EXC2 and quantified service categories F25 to F63**

Weld type	Orientation [A]	Thickness (t) or throat (a) [B] mm	Proportion of joints tested %								
			Penetrant testing (PT)			Ultrasonic testing (UT) [C]			Radiographic testing (RT) [D]		
			F25	F31	F40 to F63	F25	F31	F40 to F63	F31	F40	F50, F63
Butt	Transverse	$t < 8$	100	100	100	Not applicable	Not applicable	Not applicable	20	100	—
		$8 \leqslant t \leqslant 20$	50	100	100	100	100	100	0	20	100
		$t > 20$	100	100	100	100	100	100	0	50	100
	Longitudinal	$t < 8$	100	100	100	Not applicable	Not applicable	Not applicable	10	50	100
		$8 \leqslant t \leqslant 20$	20	50	100	10	20	100	0	10	100
		$t > 20$	20	50	100	10	20	100	0	10	100
Fillet	Transverse	$t \leqslant 20$	20	100	100	No requirement	No requirement	No requirement	No requirement		
		$t > 20$, $a \leqslant 10$	50	100	100	10	20	20			
		$t > 20$, $10 < a \leqslant 15$	100	100	100	20	50	50			
		$t > 20$, $a > 15$	100	100	100	50	100	100			
	Longitudinal	As per longitudinal butt weld									

[A] and [B] as per Table 4, footnotes A and B.

[C] Testing conditions to BS EN 1714 should be as follows:

- quantified service categories F25 and F31: Testing level B, Evaluation level DAC –14dB;
- quantified service category F40: Testing level C, Evaluation level DAC –17dB;
- quantified service categories F50 and F63: Testing level C, Evaluation level DAC –20dB;
- transverse indication scans required for longitudinal welds.

[D] Applies to in-line butt welds only. BS EN 1435:1997+A2, Class B, should be used.

Table 7 **Weld acceptance criteria for visual inspection**
All dimensions in mm

Main criterion	Imperfection type[A]		Dimensional parameter[B]		Joint type	Weld type	Acceptance limits[B), C)] to quantified service category [ ] applies to longitudinal welds only[D]			Remedial action in event of non-conformance[E]
	Description	BS EN ISO 6520-1:2007 ref no.	Symbol	BS EN ISO 10042:2005 ref no.			F20 (For F12, see footnote F)		F25 to F63	
Overall joint geometry	Weld location error	—	Dr	—	All	Fillet	Dr ±10	[±10]	As per F20	Refer to welding co-ordinator for remedial action
	Incorrect weld type	—	Dr	—	All	All	NP	[NP]	As per F20	Refer to welding co-ordinator for remedial action
	Inadequate weld length	—	Dr	—	All	All	Dr –0	[–5]	As per F20	Add extra weld length
	Linear misalignment	5071, 5072	h	3.1	In-line butt	Butt	$h \leqslant 0{,}2t$ $h \leqslant 4$	[0,3t] [5]	See Table 8	Remove existing weld, realign joint, remake preparations and check with PT, reweld to AWPS, check with UT
		507	h	—	Cruciform	All	$h \leqslant 0{,}4t$ $h \leqslant 6$	[0,4t] [6]	See Table 8	
	Angular misalignment	508	β	—	In-line butt	Butt	$\beta \leqslant 2°$	[3°]	See Table 8	Correct using approved procedure. Check with PT
	Root gap[G]	617	h	3.2	Lap, tee, cruciform	Fillet	$h \leqslant 2$	[3]	See Table 8	Refer to welding co-ordinator for remedial action
Surface notches	Crack	100 to 106	—	1.1, 1.2	All	All	NP	[NP]	As per F20	Remove imperfections by grinding to approved excavation shape, check with PT, reweld to AWPS, refer to welding co-ordinator for establishment of cause
	Lack of fusion	401, 506	—	1.8	All	All	NP	[NP]	As per F20	
	Lack of penetration (unspecified)	402	h	1.9	All	Single sided butt	NP	[$h \leqslant 0.1t$] [$h \leqslant 1$]	As per F20 [NP]	
	Large cavities	2015, 2016, 202, 510	—	—	All	Butt	NP	[NP]	As per F20	
	Undercut, under fill etc.	501, 509, 511, 515, 517	h	1.10, 1.16, 1.18	All	All	$h \leqslant 0{,}5$	[1]	See Table 8	Remove by grinding, repair to AWPS
	Pore	2017	d	1.6	All	All	$d \leqslant 2$	[2]	See Table 8	Remove to depth of 3 mm, repair to AWPS
	Toe angle	5051	α	—	All	All	$\alpha \geqslant 90°$	[90°]	See Table 8	Correct with high speed rotary burr or reweld to AWPS
	Damage	601, 603 to 606	—	—	All	All	NP	[NP]	As per F20	Grind out to smooth profile, repair by AWPS if h > 1

Table 7 **Weld acceptance criteria for visual inspection** *(continued)*
All dimensions in mm

Main criterion	Imperfection type[A]		Dimensional parameter[B]		Joint type	Weld type	Acceptance limits[B), C)] to quantified service category [ ] applies to longitudinal welds only[D]			Remedial action in event of non-conformance[E]
	Description	BS EN ISO 6520-1:2007 ref no.	Symbol	BS EN ISO 10042:2005 ref no.			F20 (For F12, see footnote F)		F25 to F63	
Loss of cross-section	Insufficient weld throat, a[H]	5213	h	1.13	Tee, lap, cruciform	Fillet	NP[G]	[h ⩽ 0.1a][G] [h ⩽ 1][G]	As per F20	Increase size using same AWPS
	Insufficient leg length, z[H]	—	h	—	Tee, lap, cruciform	Fillet	NP[G]	[h ⩽ 0.1z][G] [h ⩽ 2][G]	As per F20	
	Multiple conforming surface imperfections	201, 202, 501, 209, 511, 515, 5213	h, l, d, l_p	4.1	All	All	See footnote J	[See footnote J]	As per F20	Increase cross sectional area using methods above, depending on imperfection type
Surface condition	Spatter	602	—	—	All	All	Not permitted if surface to receive protective treatment		See Table 8	Remove by grinding or blast cleaning

A) The three digit BS EN ISO 6520-1 designation is deemed to include all four digit sub-categories.

B) Symbols are as defined by BS EN ISO 10042:2005 or BS EN ISO 6520-1:2007.
Dr = the dimension (or weld type) specified on the drawings. NP = not permitted.

C) Where more than one limit is given for an imperfection for a given quantified service category and weld orientation, all limits should apply.

D) Longitudinal welds are those not deemed to be "transverse"; see Table 4, footnote A.

E) AWPS = approved welding procedure specification for repair.

F) For joints in any orientation to F12, the imperfection limits given for longitudinal welds [ ] for F20 are applicable.

G) Where a root gap h has been observed in a tee, cruciform or corner joint, the nominal required fillet weld dimensions, as measured with a weld gauge, should be increased as follows, unless compensating penetration beyond the root has been proven: minimum required throat size a + 0.7h; minimum required leg length z + h (on affected leg only). See also footnote H.

H) Both a and z measurements should be checked, irrespective of which has been specified on the drawings. They are related as follows:

Angle between fusion faces	120°	110°	100°	90°	80°	70°	60°
z/a	2,0	1,74	1,56	1,41	1,31	1,22	1,15

See also footnote G.

J) All permitted imperfections resulting in loss of cross-section should be summed and assessed as follows:
$\Sigma hl + \Sigma 0{,}5dt \leqslant 4{,}5t$ or [⩽ 9t]. For fillet welds, "a" should be substituted for "t". Σhl should include subsurface imperfections assuming h = 3; see Table 10, footnote K.
Measurement length l_p = 100 mm.

Table 8 **Weld acceptance criteria for visual inspection for quantified service categories F25 to F63 where limits different from F20 in Table 7**
All dimensions in mm

Imperfection type [A]		**Acceptance limits according to quantified service category** [B], [C] [ ] applies to longitudinal welds only [D]										**Remedial action in event of non-conformance**
		F25		**F31**		**F40**		**F50**		**F63**		
Linear misalignment	In-line butt	$h \leqslant 0{,}15t$	[0,2t]	$h \leqslant 0{,}1t$	[0,2t]	$h \leqslant 0{,}05t$	[0,2t]	$h \leqslant 0{,}05t$	[0.2 t]	$h \leqslant 0{,}05t$	[0,05t]	As per Table 7
		$h \leqslant 4$	[5]	$h \leqslant 3$	[4]	$h \leqslant 3$	[4]	$h \leqslant 3$	[4]	$h \leqslant 1$	[1]	
	Cruci-form	$h \leqslant 0{,}3t$	[0,4t]	$h \leqslant 0{,}2t$	[0,4t]	$h \leqslant 0{,}1t$	[0,3t]	$h \leqslant 0{,}1t$	[0,2t]	Not applicable	[Not applicable]	
		$h \leqslant 5$	[6]	$h \leqslant 4$	[6]	$h \leqslant 3$	[5]	$h \leqslant 3$	[3]	Not applicable	[Not applicable]	
Angular misalignment		$\beta \leqslant 2°$	[3°]	$\beta \leqslant 1{,}5°$	[2°]	$\beta \leqslant 1°$	[2°]	$\beta \leqslant 0{,}5°$	[2°]	$\beta \leqslant 0{,}5°$	[1°]	As per Table 7
Root gap [G]		$h \leqslant 2$	[2]	$h \leqslant 2$	[2]	$h \leqslant 1$	[1]	$h \leqslant 0{,}5$	[0,5]	Not applicable	[Not applicable]	As per Table 7
Undercut, underfill		$h \leqslant 0.3$	[$h \leqslant 1$]	NP	[$h \leqslant 1$]	NP	[$h \leqslant 0{,}5$]	NP	[$h \leqslant 0{,}5$]	NP	[NP]	As per Table 7
Porosity		$d \leqslant 1{,}5$	[1,5]	$d \leqslant 1$	[1]	NP	[NP]	NP	[NP]	NP	[NP]	As per Table 7
Toe angle		$\alpha \geqslant 110°$	[90°]	$\alpha \geqslant 150°$	[90°]	$\alpha \geqslant 165°$	[110°]	$\alpha \geqslant 175°$	[110°]	$\alpha \geqslant 175°$	[175°]	As per Table 7
Spatter		Not permitted if surface to receive protective treatment		NP	[NP]	NP	[NP]	NP	[NP]	NP	[NP]	See footnote E
*Variation in root or cap longitudinal profile [B]		$\Delta h \leqslant 3$ [H]	[$\Delta h \leqslant 3$]	$\Delta h \leqslant 2$ [H]	[$\Delta h \leqslant 2$]	$\Delta h \leqslant 1$ [H]	[$\Delta h \leqslant 1$]	$\Delta h \leqslant 0{,}5$ [H]	[$\Delta h \leqslant 0{,}5$]	NP	[NP]	See footnote F

[A] Imperfection types as designated in Table 7.

[B] Symbols are as defined by BS EN ISO 10045:2005 or BS EN ISO 6520-1:2007.
NP = not permitted. Δh = the maximum variation in cap or root profile measured along weld axis over any length of 3 mm.

[C] Where more than one limit is given for an imperfection for a given quantified service category and weld orientation, all limits should apply.

[D] Longitudinal welds are those not deemed to be "transverse"; see Table 4, footnote A.

[E] For F40 and above, remove with high speed rotary burr.

[F] Correct by tapering slope to shallower angle or repair to AWPS (approved welding procedure specification for repair).

[G] Correct fillet weld sizes as per Table 7, footnote G.

[H] Transverse welds outside connection zones are exempt from this restriction (see Table 4, footnote A).

Table 9 **Weld acceptance criteria for penetrant testing**

Imperfection type	**Acceptance standard**	**Indication pattern**	**Acceptance limits according to quantified service category** [A] [ ] applies to longitudinal welds with longitudinal linear indications only [B]						**Remedial actions in event of non-conformance** [C]
			F20 (For F12, see footnote D)		**F25**		**F31 to F63**		
Surface notches identified in Table 7 and Table 8	BS EN 1289:1998	Isolated	Level 2	[Level 3]	Level 1	[Level 2]	NP	[NP]	Remove by high speed burr machining with machining marks in longitudinal direction. Repair to AWPS if non-conformance with Table 7 and Table 8 depth requirements (h).
		Grouped [E]	NP	[NP]	NP	[NP]	NP	[NP]	

[A] NP = not permitted.

[B] Longitudinal welds are those not deemed to be "transverse"; see Table 4, footnote A.

[C] AWPS = approved welding procedure specification for repair.

[D] For joints in any orientation to F12, the imperfection limits given for longitudinal welds [ ] for F20 are applicable.

[E] "Grouped" should be deemed to apply to any indications separated by less than 2.5 mm.

Table 10 **Weld acceptance criteria for ultrasonic testing with limited optional radiographic testing**
All dimensions in mm

Imperfection type [A]		**Dimensional parameter** [B]		**Location in cross-section or throat**	**Acceptance limits according to quantified service category** [B, C] [ ] applies to longitudinal welds only [D]										**Remedial action in event of non-conformance** [E]
Description	**BS EN ISO 6520-1:2007, ref no.**	**Symbol**	**BS EN ISO 10042:2005 ref no.**		**F20** (For F12, see footnote F)		**F25**		**F31**		**F40**		**F50, F63**		
Cracks	100 to 106	—	2.1, 2.2	Full depth	NP [H]	[NP] [H]	NP [H]	[NP] [H]	NP [H]	[NP] [H]	NP [J]	[NP] [J]	NP [K]	[NP] [K]	Refer to welding co-ordinator to determine cause. Remove by grinding to approved excavation shape. Check with PT. Reweld to AWPS.
Pores [G], inclusions [G], cavities [G], lack of fusion, lack of penetration	2011, 2014, 2015, 2016, 202, 203 301 to 304, 401, 402	h, l	2.3, 2.6, 2.7 to 2.12	Within 6 mm of any surface	$h \leqslant 3$ $l \leqslant 10$	[3] [20]	$h \leqslant 3$ $l \leqslant 5$	[3] [10]	NP [H] NP [H]	[h ⩽ 3] [l ⩽ 5]	NP [J] NP [J]	[NP] [J] [NP] [J]	NP [K] NP [K]	[NP] [K] [NP] [K]	
				Deeper than 6 mm from any surface	$h \leqslant 3$ $l \leqslant 1{,}5t$	[3] [3t]	$h \leqslant 3$ $l \leqslant 10$	[3] [1,5t]	$h \leqslant 3$ $l \leqslant 5$	[3] [20]	NP [H] NP [H]	[h ⩽ 3] [l ⩽ 5]	NP [J] NP [J]	[NP] [J] [NP] [J]	
		h, l, l_p, H, L	4.1	Full depth	$\Sigma l \leqslant 1{,}5t$ [L] $l_p = 100$ $H \geqslant 6$ $L \geqslant 10$	[3t] [L] [100] [6] [10]	$\Sigma l \leqslant 1{,}5t$ [L] $l_p = 100$ $H \geqslant 6$ $L \geqslant 10$	[3t] [L] [100] [6] [10]	$\Sigma l \leqslant 1{,}5t$ [L] $l_p = 100$ $H \geqslant 6$ $L \geqslant 10$	[3t] [L] [100] [6] [10]	NP NP NP NP	[Σl ⩽ 1,5t] [L] [l_p = 100] [H ⩾ 6] [L ⩾ 10]	NP NP NP NP	[NP] [NP] [NP] [NP]	
Uniformly distributed or clustered porosity	2012, 2013	—	2.4, 2.5	Full depth	Not permitted if obstructs detection or evaluation of imperfections above								NP [M]	[NP] [M]	

[A] The three digit BS EN ISO 6520-1 designation is deemed to include all four digit sub-categories.

[B] Symbols are as defined by BS EN ISO 10042:2005.
NP = not permitted. H = the clear gap between adjacent imperfections measured in through thickness direction. L = the gap between ends of adjacent imperfections measured along weld axis.

[C] Where more than one limit is given for an imperfection for a given quantified service category and weld orientation, all limits should apply.
If surface breaking imperfections are detected by UT, the criteria given in Table 7, Table 8 and Table 9 apply.

[D] Longitudinal welds are those not deemed to be "transverse"; see Table 4, footnote A.

[E] AWPS = approved welding procedure specification for repair.

[F] For joints in any orientation to F12, the imperfection limits given for longitudinal welds [ ] for F20 are applicable.

[G] Radiographic testing may be used to assist in interpretation of these imperfections.

[H] Rejection level DAC –14dB.

[J] Rejection level DAC –17dB.

[K] Rejection level DAC –20dB.

[L] If permitted surface imperfections resulting in loss of cross-section also exist, the criteria in Table 7, footnote J also apply.

[M] Also, not permitted when checked by radiographic testing.

Bibliography

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

BS EN ISO 10042, *Welding – Arc-welded joints in aluminium and its alloys – Quality levels for imperfections*

BS EN ISO 25239-1, *Friction stir welding – Aluminium – Part 1: Vocabulary*[4)]

[4)] In preparation.

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