

Arc-welded joints in aluminium and its weldable alloys — Guidance on quality levels for imperfections

The European Standard EN 30042:1994 has the status of a
British Standard

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This British Standard, having been prepared under the direction of the Welding Standards Policy Committee, was published under the authority of the Standards Board and comes into effect on 15 July 1994

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National foreword

This British Standard has been prepared under the direction of the Welding Standards Policy Committee and is the English language version of EN 30042 *Arc-welded joints in aluminium and its weldable alloys — Guidance on quality levels for imperfections*, published by the European Committee for Standardization (CEN).

EN 30042:1993 is identical with ISO 10042:1992 published by the International Organization for Standardization (ISO). EN 30042 was produced as a result of international discussion in which the UK took an active part.

There has previously been no direct British Standard equivalent to this standard. It is simply intended as guidance for designers using application standards if required. To avoid confusion, it is emphasized that the levels of detectable imperfection quoted are purely arbitrary and intended for quality control purposes only. The various levels may be referred to in whole, in part or in combination, or it may be decided that other levels are more appropriate for particular purposes. Specific requirements from this standard should be considered at the enquiry/contract stage and agreed between the contracting parties.

It is assumed that the execution of the provisions of the document is entrusted to suitably qualified and experienced persons.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, the EN title page, pages 2 to 12, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

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Descriptors: Aluminium, aluminium alloys, welding, arc welding, gas shielded welding, plasma arc welding, welded joints, butt welds, filled welds, weld defect, specifications, acceptability

English version

Arc-welded joints in aluminium and its weldable alloys — Guidance on quality levels for imperfections

(ISO 10042:1992)

Assemblages en aluminium et alliages
d'aluminium soudables soudés à l'arc —
Guide des niveaux d'acceptation des défauts
(ISO 10042:1992)

Lichtbogenschweißverbindungen an
Aluminium und seinen schweißgeeigneten
Legierungen — Richtlinie für die
Bewertungsgruppen von Unregelmäßigkeiten
(ISO 10042:1992)

This European Standard was approved by CEN on 1994-05-12. CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CEN

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Comité Européen de Normalisation
Europäisches Komitee für Normung

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Foreword

The text of the International Standard ISO 10042:1992 prepared by ISO/TC 44, Welding and allied processes, was submitted to the Unique Acceptance Procedure (UAP) and was approved as EN 30042 on 1994-05-12 without any modification.

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 1994, and conflicting national standards shall be withdrawn at the latest by November 1994.

This European Standard has been prepared under a mandate given to CEN by the Commission of the European Communities and the European Free Trade Association, and supports essential requirements of EC Directive(s).

According to the CEN/CENELEC Internal Regulations, the following countries are bound to implement this European Standard: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

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Introduction

This International Standard should be used as a reference in the drafting of application codes and/or other application standards. It may be used within a total quality system for the production of satisfactory welded joints. It provides three sets of dimensional values from which a selection can be made for a particular application. The quality level necessary in each case should be defined by the application standard or the responsible designer in conjunction with the manufacturer, user and/or other parties concerned. The level shall be prescribed before the start of production, preferably at the enquiry or order stage. For special purposes, additional details will possibly need to be prescribed.

The quality levels given in this International Standard are intended to provide basic reference data. They are not specifically related to any particular application. They refer to the types of welded joints in a fabrication and not to the complete product or component itself. It is possible, therefore, for different quality levels to be applied to individual welded joints in the same product or component.

Quality levels are listed in Table 0.1.

Table 0.1 — Quality levels for weld imperfections

Level symbol	Quality level
D	Moderate
C	Intermediate
B	Stringent

The three quality levels are arbitrarily identified as D, C and B and are intended to cover the majority of practical applications.

It would normally be hoped that for a particular welded joint the dimensional limits for imperfections could all be covered by specifying one quality level. In some cases, however, e.g. for certain types of aluminium and structures as well as for fatigue loading or leak tightness applications, it may be necessary to specify different quality levels for different imperfections in the same welded joint or to include additional requirements.

The choice of quality level for any application should take account of design considerations, subsequent processing (e.g. surfacing), mode of stressing (e.g. static, dynamic), service conditions (e.g. temperature, environment) and consequences of failure. Economic factors are also important and should include not only the cost of welding but also that of inspection, test and repair.

Although this International Standard includes types of imperfections relevant to the arc welding processes given in clause 1, only those which are applicable to the process and application in question need to be considered.

Imperfections are quoted in terms of their actual dimensions and their detection and evaluation can require the use of one or more methods of non-destructive testing. The detection and sizing of imperfections is dependent on the inspection methods and the extent of testing specified in the application standard or contract.

This International Standard does not include details of recommended methods of detection and sizing and therefore it needs to be supplemented by requirements for examination, inspection and testing. It should be appreciated that methods of non-destructive examination may not be able to give the detection, characterization and sizing necessary for use within certain types of imperfections in Table 1.

Although this International Standard covers a material thickness range of 3 mm to 63 mm, it can possibly be applied to thicker or thinner joints provided consideration is given to those technical factors which influence the situation.

1 Scope

This International Standard provides guidance on levels of imperfections in arc-welded joints in aluminium and its weldable alloys.

Three levels are given in such a way as to permit application for a wide range of welded fabrications. The levels refer to production quality and not to the fitness-for-purpose (see 3.1) of the product manufactured.

This International Standard applies to

- aluminium and weldable aluminium alloys;
- the following processes in accordance with ISO 4063:
 - 131 gas-shielded metal-arc welding (MIG);
 - 141 gas-shielded welding with non-consumable electrode (TIG);
 - 15 plasma arc welding;
- manual, mechanized and automatic processes;
- all welding positions;
- butt welds, fillet welds and welds on branch connections;
- materials in the thickness range 3 mm to 63 mm.

When significant deviations from the joint geometries and dimensions described in this International Standard are present in the welded product, it is necessary to evaluate to what extent the provisions of this International Standard can apply.

Metallurgical aspects, e.g. grain size, are not covered by this International Standard.

For the purposes of this International Standard the term aluminium covers aluminium and its weldable alloys.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards. ISO 2553:1992, *Welded, brazed and soldered joints — Symbolic representation on drawings*.

ISO 4063:1990, *Welding, brazing, soldering and braze welding of metals — Nomenclature of processes and reference numbers for symbolic representation on drawings*.

ISO 6520:1982, *Classification of imperfections in metallic fusion welds, with explanations*.

3 Definitions

For the purposes of this International Standard, the following definitions apply.

3.1 fitness-for-purpose

a product is fit for its intended purpose when it functions satisfactorily in service during its stipulated lifetime. The product may deteriorate in service, but not to such a degree that fracture and subsequent failure occurs. Products can, of course, be misused or overloaded; it is presumed that the actual conditions during service correspond to the intended conditions, including statistical variations, e.g. live loads.

3.2 Weld thickness

3.2.1 fillet weld thickness, a ; nominal throat thickness

height of the largest isosceles triangle that can be inscribed in the weld section (see ISO 2553).

NOTE 1 In countries in which the leg length, z , is used as the dimension of a fillet weld, the limits for imperfections may be reformulated so that they refer to the leg length.

3.2.2

butt weld thickness, s

minimum distance from the surface of the part to the bottom of the penetration, which cannot be greater than the thickness of the thinner of the parts (see ISO 2553)

3.3

short imperfection

one or more imperfections of total length not greater than 25 mm in any 100 mm length of the weld or a maximum of 25 % of the weld length for a weld shorter than 100 mm

3.4

long imperfection

one or more imperfections of total length greater than 25 mm in any 100 mm length of the weld or a minimum of 25 % of the weld length for a weld shorter than 100 mm

3.5

projected area

area given by length of weld examined multiplied by the maximum width of weld

3.6

surface crack area

area to be considered after fracture

4 Symbols

The following symbols are used in Table 1:

A	area of gas cavity
a	nominal fillet weld throat thickness (fillet thickness)
b	width of weld reinforcement
d	diameter of pore
h	size (height or width) of imperfection
l	length of imperfection
s	nominal butt weld thickness or, in the case of partial penetration, the prescribed depth of penetration
t	wall or plate thickness
z	nominal leg length of fillet welds (in case of isosceles right angle triangular section $z = a \cdot \sqrt{2}$).

5 Evaluation of welds

Limits for imperfections are given in Table 1.

A welded joint should normally be evaluated separately for each individual type of imperfection (Nos. 1 to 23).

Different types of imperfection occurring at any cross-section of the joint can possibly need special consideration (see No. 24).

Table 1 — Limits for imperfections

No.	Imperfection designation	ISO 6520 reference	Remarks	Limits for imperfections for quality levels		
				Moderate D	Intermediate C	Stringent B
1	Cracks	100	All types of cracks except micro cracks ($hl \leq 1\text{mm}^2$), crater cracks see No. 2	Not permitted		
2	Crater crack	104		$h \leq 0,2\text{ s}$ or $0,2\text{ a}$	Not permitted	
3	Gas cavity	201	The term “gas cavity” includes: uniformly distributed porosity, localized porosity, linear porosity and gas pore.	For 100 mm length:		
				$A \leq 8\text{ s}$ or 8 a mm^2	$A \leq 4\text{ s}$ or 4 a mm^2	$A \leq 2\text{ s}$ or 2 a mm^2
4	Gas pore	2011	The total pore area within the cluster should be summed: an envelope surrounding all the pores or a circle with a diameter corresponding to the weld width.	$d \leq 0,5\text{ s}$ or $0,5\text{ a}$ max. 5,5 mm	$d \leq 0,3\text{ s}$ or $0,3\text{ a}$ max. 4,5 mm	$d \leq 0,25\text{ s}$ or $0,25\text{ a}$ max. 3,5 mm
5	Uniformly distributed porosity	2012	The permitted porous area should be local. The possibility of masking of other imperfections should be taken Into consideration.	$d \leq 0,5\text{ mm} + 0,035\text{ s}$ or $0,035\text{ a}$ max. 2 mm	$d \leq 0,5\text{ mm} + 0,02\text{ s}$ or $0,02\text{ a}$ max. 1,5 mm	$d \leq 0,5\text{ mm} + 0,01\text{ s}$ or $0,01\text{ a}$ max. 1 mm
6	Localized (clustered) porosity	2013		$d \leq 0,5\text{ mm} + 0,05\text{ s}$ or $0,05\text{ a}$ max. 3 mm	$d \leq 0,5\text{ mm} + 0,035\text{ s}$ or $0,035\text{ a}$ max. 2 mm	$d \leq 0,5\text{ mm} + 0,02\text{ s}$ or $0,02\text{ a}$ max. 1,5 mm
7	Surface pore (visible gas cavity)	2017		For 100 mm length		
				$A \leq 2\text{ t mm}^2$ $d \leq 0,5\text{ mm} + 0,035\text{ s}$ or $0,035\text{ a}$ max. 2 mm	$A \leq 1\text{ t mm}^2$ $d \leq 0,5\text{ mm} + 0,02\text{ s}$ or $0,02\text{ a}$ max. 1,5 mm	$A \leq 0,5\text{ t mm}^2$ $d \leq 0,5\text{ mm} + 0,01\text{ s}$ or $0,01\text{ a}$ max. 1 mm
8	Solid inclusions (other than copper and tungsten)	300	Solid inclusions include inclusions for oxides. If several inclusions $h_1, h_2, h_3 \dots$ exist in a cross section, the summation is $\Sigma h = h_1 + h_2 + h_3 \dots$	Long imperfections: Not permitted		
				Short imperfections		
				$\Sigma h \leq 0,1\text{ s}$ or $0,1\text{ a}$ max. 3 mm	max. 1,5 mm	Not permitted
9	Tungsten inclusions	3041		$h \leq 0,1\text{ s}$ or $0,1\text{ a}$ max. 3 mm		$h \leq 0,05\text{ s}$ or $0,05\text{ a}$ max. 0,8 mm
10	Copper inclusions	3042		Not permitted		
11	Lack of fusion (incomplete fusion)	401	If lack of fusion occurs at several places $h_1, h_2, h_3 \dots$ the summation is $\Sigma h = h_1 + h_2 + h_3 \dots$	Long imperfections: Not permitted		
				Short imperfections:		
				$\Sigma h \leq 0,1\text{ s}$ or $0,1\text{ a}$ max. 3 mm	max. 1,5 mm	Not permitted

Table 1 — Limits for imperfections

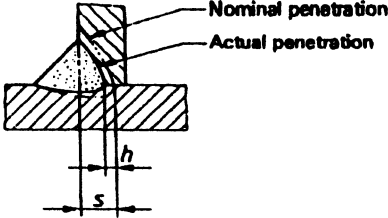
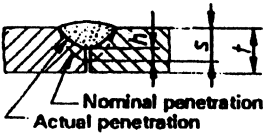
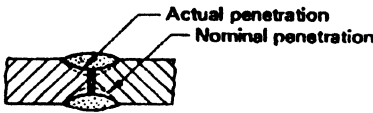
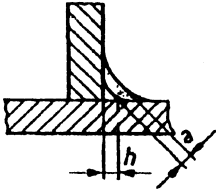
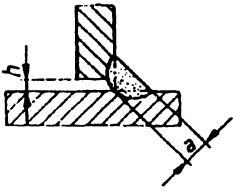
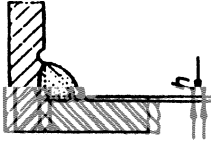
No.	Imperfection designation	ISO 6520 reference	Remarks	Limits for imperfections for quality levels		
				Moderate D	Intermediate C	Stringent B
12	Lack of penetration (incomplete penetration)	402	 Figure A  Figure B.  Figure C	A few permitted, no systematic ones. $h \leq 0,4 s$ max. 3 mm	$h \leq 0,2 s$ max. 2 mm	Not permitted
12.1	Lack of penetration (incomplete penetration), fillet welds	—		Long imperfections: Not permitted		
				$h \leq 0,3 a$ max. 2 mm	$h \leq 0,2 a$ max. 1,5 mm	$h \leq 0,1 a$ max. 1 mm
13	Bad fit-up, fillet welds	—	An excessive or insufficient gap between the parts to be joined  Gaps exceeding the appropriate limit may in certain cases be compensated for by a corresponding increase in the throat	$h \leq 1 \text{ mm} + 0,2 a$ max. 4 mm	$h \leq 0,5 \text{ mm} + 0,15 a$ max. 3 mm	$h \leq 0,5 \text{ mm} + 0,1 a$ max. 2 mm
14	Undercut	5011 5012	Smooth transition is required  	Long imperfections: $h \leq 0,6 \text{ mm}$		
				Short imperfections: $h \leq 1,5 \text{ mm}$		
					$h \leq 0,4 \text{ mm}$	$h \leq 0,2 \text{ mm}$
					$h \leq 1 \text{ mm}$	$h \leq 0,5 \text{ mm}$

Table 1 — Limits for imperfections

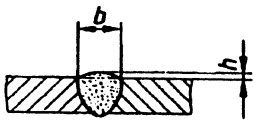
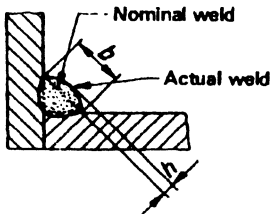
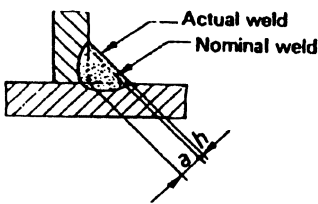
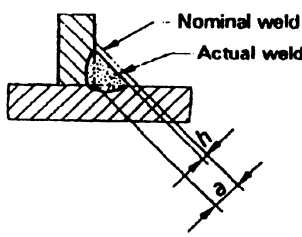
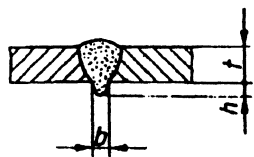
No.	Imperfection designation	ISO 6520 reference	Remarks	Limits for imperfections for quality levels		
				Moderate D	Intermediate C	Stringent B
15	Excess weld metal ^a	502	Smooth transition is required 	$h \leq 1,5 \text{ mm} + 0,2 b$ max. 10 mm	$h \leq 1,5 \text{ mm} + 0,15 b$ max. 7 mm	$h \leq 1,5 \text{ mm} + 0,1 b$ max. 5 mm
16	Excessive convexity	503		$h \leq 1,5 \text{ mm} + 0,3 b$ max. 5 mm	$h \leq 1,5 \text{ mm} + 0,15 b$ max. 4 mm	$h \leq 1,5 \text{ mm} + 0,1 b$ max. 3 mm
17	Fillet weld having a throat thickness greater than the nominal value	—	For many applications a throat thickness greater than the nominal one may not be a reason for rejection 	$h \leq 1 \text{ mm} + 0,3 a$ max. 7 mm	$h \leq 1 \text{ mm} + 0,2 a$ max. 6 mm	$h \leq 1 \text{ mm} + 0,15 a$ max. 5 mm
18	Fillet weld having a throat thickness smaller than the nominal value	—	A fillet weld with an apparent throat thickness smaller than prescribed should not be regarded as being imperfect if the actual throat thickness with a compensating greater depth of penetration complies with the nominal value 	Long imperfections: Not permitted		
				$h \leq 0,3 a$ max. 2 mm	$h \leq 0,2 a$ max. 1,5 mm	$h \leq 0,1 a$ max. 1 mm
19	Excessive penetration	504		$h \leq 5 \text{ mm}$	$h \leq 4 \text{ mm}$	$h \leq 3 \text{ mm}$

Table 1 — Limits for imperfections

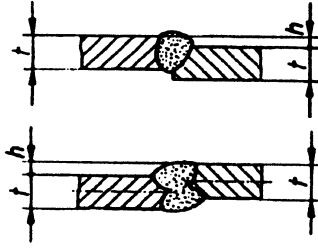
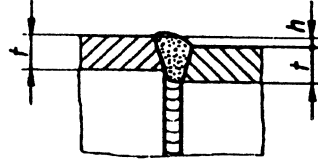
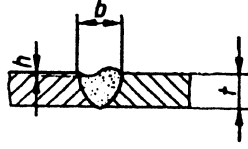
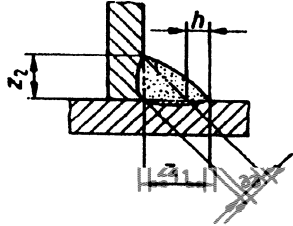
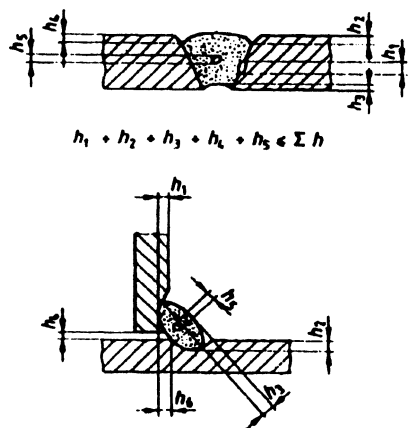
No.	Imperfection designation	ISO 6520 reference	Remarks	Limits for imperfections for quality levels		
				Moderate D	Intermediate C	Stringent B
20	Linear misalignment	507	The limits relate to deviations from the correct position. Unless otherwise specified, the correct position is that when the centre-lines coincide (see also clause 1). t refers to the smaller thickness  Figure A — Plates and longitudinal welds	$h \leq 0,5 \text{ mm} + 0,25 t$ max. 4 mm	$h \leq 0,5 \text{ mm} + 0,15 t$ max. 3 mm	$h \leq 0,5 \text{ mm} + 0,1 t$ max. 2,5 mm
			 Figure B — Circumferential welds	max. 4 mm	$h \leq 0,5 t$ max. 3 mm	max. 2,5 mm
21	Incompletely filled groove	511	Smooth transition is required. 	Long imperfections: Not permitted		
				$h \leq 0,2 t$ max. 2 mm	$h \leq 0,1 t$ max. 1,5 mm	$h \leq 0,05 t$ max. 1 mm
22	Excessive asymmetry of fillet weld	512	It is assumed that an asymmetric fillet weld has not been expressly prescribed. 	$h \leq 3 \text{ mm} + 0,3 a$	$h \leq 2 \text{ mm} + 0,25 a$	$h \leq 1,5 \text{ mm} + 0,2 a$
23	Root concavity	515	Smooth transition is required. 	Long imperfections: Not permitted		
	Shrinkage groove	5013		$h \leq 0,2 t$ max. 2 mm	$h \leq 0,1 t$ max. 1,5 mm	$h \leq 0,05 t$ max. 1 mm

Table 1 — Limits for imperfections

No.	Imperfection designation	ISO 6520 reference	Remarks	Limits for imperfections for quality levels		
				Moderate D	Intermediate C	Stringent B
24	Multiple imperfections in any cross section ^b	—	For thicknesses $s \leq 10$ mm or $a \leq 10$ mm, special consideration may be necessary.  $h_1 + h_2 + h_3 + h_4 + h_5 \leq \Sigma h$ $h_1 + h_2 + h_3 + h_4 + h_5 + h_6 \leq \Sigma h$	Maximum total height of short imperfections Σh 0,3 s or 0,3 a max. 10 mm	0,25 s or 0,25 a max. 10 mm	0,2 s or 0,2 a max. 10 mm
^a Similar requirements may be used as a guideline for the heights of Individual runs in multirun welds, using the bead instead of reinforcement width. ^b See annex A.						

Annex A (informative)

Additional information and guidelines for use of this International Standard

This International Standard specifies requirements for three levels of acceptance for imperfections in joints of aluminium and its weldable alloys as listed in clause 1 and for weld thicknesses of 3 mm to 63 mm. It may be used, where applicable, for other fusion welding processes or weld thicknesses.

Very often different parts are produced for different applications but to similar requirements. The same requirements should, however, apply to identical parts produced in different workshops, to ensure that work is carried out using the same criteria. The consistent application of this International Standard is one of the fundamental cornerstones of a quality assurance system for use in the production of welded structures.

In Table 1, the figures for multiple imperfections (No. 24) show a theoretical possibility of superimposed individual imperfections. In such a case the total summation of all permitted deviations should be restricted by the stipulated values for the different quality levels. However, the value of a single imperfection may exceed h , e.g. for a single pore.

The requirements given in this International Standard should not be treated as absolute limits but rather as limits which should not be exceeded with more than a defined probability. It should be noted that imperfections exceeding the size limits given are often present in a weld without impairing its fitness-for-purpose.

When determining the quality level it should be taken into consideration that:

- a) Crater, crater cracks, excess weld metal, undercuts and root concavities can reduce the ability of a weld to withstand dynamic loads.
- b) Misalignment influences the way in which the weld behaves under stress.
- c) Gas pores can cause failures when surfacing is carried out.
- d) Incomplete fusion and incomplete penetration can affect the maximum static load the weld will support.
- e) Group B entails higher production and testing costs than group C or D.

The stipulated quality level should therefore not only comply with the technical requirements but also permit cost-effective production.

This International Standard should be used as a reference standard for standards covering a specific application such as fabrication of engineering.

In addition, quality levels may be used for assessing welds during approval testing, e.g. welder approval tests and procedure qualification tests. The use of quality level B (stringent requirements) is recommended for approval testing of welders in accordance with ISO 9606-1^[1] and ISO 9606-2^[2] and for procedure tests with ISO 9956-3^[3] and ISO 9956-4^[4].

This International Standard may be used in conjunction with a catalogue of realistic illustrations showing the size of the permissible imperfections for the various quality levels by means of photographs showing the face and root side and/or reproductions of radiographs and of photomacrographs showing the cross-section of the weld. This catalogue may be used with reference cards to assess the various imperfections and may be employed when opinions differ as to the permissible size of imperfections.

Annex B (informative)

Bibliography

- [1] ISO 9606-1:—, *Approval testing of welders — Fusion welding — Part 1: Steels*¹⁾.
- [2] ISO 9606-2:—, *Approval testing of welders — Fusion welding — Part 2: Aluminium and aluminium alloys*¹⁾.
- [3] ISO 9956-3:—, *Specification and approval of welding procedures for metallic materials — Part 3: Welding procedure tests for the arc welding of steels*¹⁾.
- [4] ISO 9956-4:—, *Specification and approval of welding procedures for metallic materials — Part 4: Welding procedure tests for the arc welding of aluminium and its alloys*¹⁾.

¹⁾ To be published.

Annex ZA (normative)**Normative references to international publications with their relevant European publications**

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applied (including amendments).

Publication	Year	Title	EN/HD	Date
ISO 2553	1992	<i>Welded, brazed and soldering joints — Symbolic representation on drawings</i>	EN 22553	1994
ISO 4063	1990	<i>Welding, brazing, soldering and braze welding of metals — Nomenclature of processes and reference numbers for symbolic representations on drawings</i>	EN 24063	1992
ISO 6520	1982	<i>Classification of imperfections in metallic welds, with explanations</i>	EN 26520	1991

National annex NA (informative)

Committees responsible

The United Kingdom participation in the preparation of this European Standard was entrusted by the Welding Standards Policy Committee (WEE/-) to Technical Committee WEE/-/1 upon which the following bodies were represented:

Associated Offices Technical Committee
British Constructional Steelwork Association Ltd.
British Railways Board
British Steel Industry
Power Generation Contractors' Association (BEAMA Ltd.)
Process Plant Association
Railway Industry Association of Great Britain
Welding Manufacturers' Association (BEAMA Ltd.)
Welding Institute
Chairman of WEE/36
Chairman of WEE/26
Chairman of WEE/18
Chairman of WEE/34
Chairman of WEE/39
Chairman of WEE/6

National annex NB (informative)

Cross-references

Publication referred to	Corresponding British Standard
ISO 4063:1990	BS EN 24063:1992 <i>Welding, brazing, soldering and braze welding of metals — Nomenclature of processes and reference numbers for symbolic representation on drawings</i>
ISO 6520:1982	BS EN 26520:1992 <i>Classification of imperfections in metallic fusion welds, with explanations</i>

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