
Welding — Recommendations for welding of metallic materials —

Part 2: Arc welding of ferritic steels

*Soudage — Recommandations pour le soudage des matériaux
métalliques —
Partie 2: Soudage à l'arc des aciers ferritiques*

ISO/TR 17671-2:2002

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Printed in Switzerland

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

Attention is drawn to the possibility that some of the elements of this part of ISO/TR 17671 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TR 17671-2 was prepared by Technical Committee ISO/TC 44, *Welding and allied processes*, Subcommittee SC 10, *Unification of requirements in the field of metal welding*.

ISO/TR 17671 consists of the following parts, under the general title *Welding — Recommendations for welding of metallic materials*:

- *Part 1: General guidance for arc welding*
- *Part 2: Arc welding of ferritic steels*
- *Part 3: Arc welding of stainless steels*
- *Part 4: Arc welding of aluminium and aluminium alloys*

Introduction

This part of ISO/TR 17671 supplements part 1. It is issued with several annexes in order that it can be extended to cover the different types of steel which are produced to all the International steel standards for ferritic steels (see clause 5).

This part of ISO/TR 17671 gives general guidance for the satisfactory production and control of welds in ferritic steels. Details concerning the possible detrimental phenomena which can occur are given with advice on methods by which they can be avoided. This part of ISO/TR 17671 is generally applicable to all ferritic steels and is appropriate regardless of the type of fabrication involved, although the application standard can have additional requirements.

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Welding — Recommendations for welding of metallic materials —

Part 2:

Arc welding of ferritic steels

1 Scope

This part of ISO/TR 17671 gives guidance for manual, semi-mechanized, mechanized and automatic arc welding of ferritic steels (see clause 5), excluding ferritic stainless steels, in all product forms.

2 References

ISO 9692-1, *Welding and allied processes — Recommendations for joint preparation — Part 1: Manual metal-arc welding, gas-shielded metal-arc welding and gas welding of steels*

ISO 9956-2, *Specification and approval of welding procedures for metallic materials — Part 2: Welding procedure specification for arc welding*

ISO 13916, *Welding — Guidance on the measurement of preheating temperature, interpass temperature and preheat maintenance temperature*

ISO/TR 15608:2000, *Welding — Guidelines for a metallic material grouping system*

ISO/TR 17671-1:—, *Welding — Recommendations for welding of metallic materials — Part 1: General guidance for arc welding*

3 Terms and definitions

For the purposes of this part of ISO/TR 17671, the terms and definitions given in ISO/TR 17671-1 and the following apply.

3.1

cooling time

$t_{8/5}$

time taken, during cooling, for a weld run and its heat affected zone to pass through the temperature range from 800 °C to 500 °C

3.2

run out length

length of a run produced by the melting of a covered electrode

3.3

run out ratio

R_r

ratio of the run out length to the length of electrode consumed

3.4 shape factor

F_x
influence of the form of a weld on the cooling time, $t_{8/5}$

NOTE In the case of two-dimensional heat flow it is called F_2 and in the case of three-dimensional heat flow it is called F_3 .

3.5 three-dimensional heat flow

heat introduced during welding, which flows parallel and perpendicular to the plate surface

3.6 transition thickness

d_t
plate thickness at which the transition from three-dimensional to two-dimensional heat flow takes place

3.7 two-dimensional heat flow

heat introduced during welding, which flows only parallel to the plate surface

3.8 preheat maintenance temperature

T_m
minimum temperature in the weld zone, which should be maintained if welding is interrupted

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4 Symbols and abbreviated terms

4.1 Symbols

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See Table 1.

Table 1 — Symbols of the terms used

Symbol	Term	Unit
c	Specific heat capacity	J/kg·K
d	Thickness of plate	mm
d_t	Transition thickness	mm
D	Diameter	mm
F_2	Shape factor for two-dimensional heat flow	1
F_3	Shape factor for three-dimensional heat flow	1
Q	Heat input	kJ/mm
R_r	Run out ratio	1
$t_{8/5}$	Cooling time (from 800 °C to 500 °C)	s
t	Melting time of an electrode	s
T_i	Interpass temperature	°C
T_m	Preheat maintenance temperature	°C
T_o	Initial plate temperature	°C
T_p	Preheat temperature	°C
T_t	Impact transition temperature	°C
λ	Thermal conductivity	J/cm·K·s
ρ	Density	kg/m ³

4.2 Abbreviations

CE	Carbon equivalent (see A.2.1), expressed as a percentage
CET	Carbon equivalent (see A.3.2), expressed as a percentage
HAZ	Heat affected zone
HD	Diffusible hydrogen content in millilitres per 100 g of deposited weld metal
UCS	Unit of crack susceptibility

5 Parent metal

This part of ISO/TR applies to ferritic steels excluding ferritic stainless steels. This includes steels referenced in groups 1 to 7 of ISO/TR 15608:2000. When ordering steel it may be necessary to specify requirements concerning weldability, which can involve specifying additional requirements to those given in the relevant steel standard.

6 Weldability factors

The properties and the quality of welds are particularly influenced by the welding conditions. Thus, the following factors should be taken into consideration:

- joint design;
- hydrogen-induced cracking;
- toughness and hardness of the heat affected zone (HAZ);
- solidification cracking;
- lamellar tearing;
- corrosion.

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The mechanical and technological properties, in particular the hardness and toughness of the heat affected zone in a narrowly delineated area, can be influenced to a greater or lesser degree, compared with the properties of the parent metal and depend on the welding conditions. Experience and tests indicate that, not only the properties of the narrow affected zone of lower strength and better flexibility, but also the load distribution effect of the tougher adjacent zones should be taken into account when assessing the ductility and safety against fracture of welded joints as this could affect the choice of steel.

7 Handling of welding consumables

When special protection or other treatment during storage or immediately prior to use is recommended by the consumables' manufacturer, these consumables should be treated in accordance with the conditions detailed by the manufacturer.

When drying or baking, consumables should be removed from their original containers. After removal from the oven, the consumables should be protected from exposure to conditions conducive to moisture absorption. In the case of welding consumables that have been specially packaged, e.g. using vacuum or other moisture-resistance means, advice from the consumables' manufacturer should be sought as to further steps required for drying and baking.

If controlled hydrogen levels are required, it is recommended that welders be issued with electrodes in heated quivers or sealed containers.

Drying ovens, e.g. for welding consumables, should be provided with a means of measuring the oven temperature.

8 Weld details

8.1 Butt welds

Butt joints between parts of unequal cross-section should be made and subsequently shaped such that a severe stress concentration at the junction is avoided.

Some examples of joint preparations for use with metal-arc welding with covered electrodes and gas-shielded metal-arc welding are given in ISO 9692-1.

Partial penetration butt joints may be permitted dependant on the design specification. Consideration should be given to the choice of weld preparation and welding consumables in order to achieve the specified throat thickness.

Under fatigue conditions, partial penetration joints or the use of permanent backing material may be undesirable.

Backing material may consist of another steel part of the structure when this is appropriate. When it is not appropriate to use part of the structure as backing material, the material to be used should be such that detrimental effects on the structure are avoided and should also be agreed in the design specification.

Care should be taken when using copper as a backing material as there is a risk of copper pick-up in the weld metal.

Where temporary or permanent backing material is used, the joint should be arranged in such a way as to ensure that complete fusion of the parts to be joined is readily achieved.

Wherever the fabrication sequence allows, tack welds, attaching permanent backing should be positioned for subsequent incorporation into the weld (see clause 14 of ISO/TR 17671-1:—).

8.2 Fillet welds

Unless otherwise specified, the edges and surfaces to be joined by fillet welding should be in as close contact as possible since any gap may increase the risk of cracking. Unless otherwise specified, the gap should not exceed 3 mm. Consideration should be given to the need to increase the throat of the fillet weld to compensate for a large gap.

Unless otherwise specified, welding should not start/stop near corners, instead, it should be continued around the corners.

9 Welds in holes or slots

Due to the risk of cracking, holes or slots should not be filled with weld metal unless required by the design specification. Holes or slots that are required to be filled with weld metal shall only be filled after the first run has been found to be acceptable (see also B.4).

10 Preparation of joint face

10.1 General

Any large notches or any other errors in joint geometry which might occur should be corrected by applying a weld deposit according to an approved welding procedure. Subsequently, they should be ground smooth and flush with the adjacent surface to produce an acceptable finish.

Prefabrication primers (shop primers) may be left on the joint faces provided that it is demonstrated that they do not adversely affect the welding.

10.2 Fusion faces

When shearing is used, the effect of work hardening should be taken into account and precautions should be taken to ensure that there is no cracking of the edges.

Single- and double-U and single-J weld preparations usually have to be machined. In assessing the methods of preparation and type of joint, the requirements of the chosen welding process should be taken into account.

10.3 Unwelded faces

Where a cut edge is not a fusion face, the effect of embrittlement from shearing, thermal cutting or gouging should not be such as to adversely affect the workpiece.

Local hardening can be reduced by suitable thermal treatment or removed by mechanical treatment. The removal of 1 mm to 2 mm from a cut face normally eliminates the hardened layer. When using thermal cutting, local hardening can be lessened by a reduction in usual cutting speed or by preheating before cutting. If necessary the steel supplier should be consulted for recommendations on achieving a reduction in hardness.

U and J weld preparations as compared with V and bevel weld preparations serve to reduce distortion by virtue of the smaller amount of weld metal required. Likewise, double preparations are better than single preparations in that the weld metal can be deposited in alternate runs on each side of the joint. In the control of distortion, accuracy of preparation and fit-up of parts are important considerations, as well as a carefully planned and controlled welding procedure.

11 Alignment of butt welds before welding

Unless specified otherwise (e.g. in a welding procedure specification or an application standard), the root edges or root faces of butt joints should not be out of alignment by more than 25 % of the thickness of the thinner material, for material up to and including 12 mm thick, or by more than 3 mm for material thicker than 12 mm.

For certain applications and welding processes, closer tolerances may be necessary.

NOTE An application standard means a relevant product standard.

12 Pre-heating

The points of temperature measurement should be in accordance with ISO 13916 except that for all thicknesses the distance for measurement should be at least 75 mm from the weld centre line.

Particular attention should be paid to the need for pre-heating when making low heat input welds, e.g. tack welds.

13 Tack welds

It is recommended that the minimum length of a tack weld be 50 mm, but for material thicknesses less than 12 mm the minimum length of a tack weld should be four times the thicker part. For materials of thickness greater than 50 mm or of yield strength over 500 N/mm² consideration should be given to increasing the length and size of tack welds, which may involve the use of a two-run technique. Consideration should also be given to the use of lower strength and/or higher ductility consumables when welding higher alloy steel.

14 Temporary attachments

If a thermal process is used to remove a temporary attachment or run on/off pieces after welding, sufficient attachment or run on/off pieces should be left to allow subsequent removal of the heat-affected material by careful grinding.

15 Heat input

Heat input is calculated from the weld travel speed (see clause 19 of ISO/TR 17671-1:—). When weaving with manual metal-arc welding, the weave width should be restricted to three times the diameter of the core rod.

NOTE This limitation of weave width refers only to the calculation of the heat input.

For multi-wire arc welding, the heat input is calculated as the sum of the heat input for each individual wire using the individual current and voltage parameters.

16 Welding procedure specification

The welding procedure specification should comply with ISO 9956-2 and include the following:

- a) whether shop or site welding;
- b) maximum combined thickness (see A.2.4) if annex A.2 is applied; plate thickness if annex A.3 is applied;
- c) heat input (see clause 15);
- d) hydrogen scale (see A.2.3 and A.3.2);
- e) tack welds (see clause 13).

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17 Identification

Where the use of hard stamp marks is required by the contract, guidance on their location and size should be given. Indentations used for marking in radiographic examination require equal consideration.

18 Inspection and testing

Due to the risk of delayed cracking, a period of at least 16 h is generally required before the final inspection is made of as-welded fabrications. The minimum time may be reduced for thin materials below 500 N/mm² yield strength or increased for materials of thickness greater than 50 mm or of yield strength over 500 N/mm². Whatever period is used it should be stated in the inspection records.

Welds that have been heat-treated to reduce the hydrogen content or which have been stress relieved, need no additional time interval following the heat treatment before final inspection is made.

Tungsten inert gas welding (TIG) and other remelting processes, if required for post-weld treatment, should be performed before final inspection.

Welds which are to be inspected and approved should not be painted or otherwise treated until they have been accepted.

19 Correction of non-conforming welds

All welds which do not conform to the design specification should be corrected.

NOTE Fracture mechanics or other assessment techniques may be used to determine whether a non-conforming weld needs to be corrected.

20 Correction of distortion

The temperature of heated areas, measured by appropriate methods, should be in accordance with the recommendations of the material supplier or the design specification.

21 Post-weld heat treatment

When post-weld heat treatment of welds is required but no application standard exists, the heat treatment details should be stated in the design specification taking account of the effect on the properties of the parent metal, HAZ and weld metal.

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Annex A

Avoidance of hydrogen cracking (also known as cold cracking)

A.1 General

This annex gives recommendations for the avoidance of hydrogen cracking.

In preparing this annex, full account was taken of the fact that many methods have been proposed for predicting preheat temperatures to avoid hydrogen cracking in non-alloyed, fine grained and low alloy steel weldments. Examples are given in IIW documents IX-1602-90 and IX-1631-91. Two methods are included in this annex as A.2 and A.3. Method A given in A.2 is based on extensive experience and data which is mainly, but not exclusively, for carbon manganese type steels. Method B given in A.3 is based on experience and data which is mainly, but not exclusively, for low alloy, high strength steels. The differences in origin and experience used to develop these two methods can be used as a guide as to their application.

The method described under A.4 is used for creep resistant and low temperature steels.

The recommendations apply only to normal fabrication restraint conditions. Higher restraint situations may need higher preheat temperatures or other precautions in order to prevent hydrogen cracking.

Clauses A.2 and A.3 refer to welding of parent metal at temperatures above 0 °C. When welding is carried out below this temperature it is possible that special requirements will be needed.

Alternative procedures to those derived from this annex may be used, e.g. lower preheat temperatures, provided they are supported by evidence of their effectiveness. The evidence should include all the factors also considered for the welding procedures as given in this annex.

A.2 Method A for the avoidance of hydrogen cracking in non-alloyed, fine grained and low alloy steels

A.2.1 Parent metal

Clause A.2 covers non-alloyed, fine grained and low alloy steels.

The range of chemical composition in percentage by weight of the main alloy constituents is:

— carbon	0,05 to 0,25
— silicon	0,8 max.
— manganese	1,7 max.
— chromium	0,9 max.
— copper	1,0 max.
— nickel	2,5 max.
— molybdenum	0,75 max.
— vanadium	0,20 max.

The determination of safe, but economic, preheating levels for the prevention of hydrogen cracking is critically dependent on an accurate knowledge of parent metal composition and carbon equivalent, CE, and on the weld metal composition (see A.2.9).

CE values for parent material are calculated using the following formula:

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \text{ in } \% \quad (A.1)$$

Clause A.2 is applicable to steels with a CE in the range 0,30 to 0,70.

If, of the elements in this formula, only carbon and manganese are stated on the mill sheet for carbon and carbon manganese steels, then 0,03 should be added to the calculated value in order to allow for residual elements. Where steels of different CE or grade are being joined, the higher CE value should be used.

This CE formula may not be suitable for boron-containing steels.

A.2.2 Factors affecting cracking

The occurrence of hydrogen cracking depends on a number of factors; composition of the steel, the welding procedure, welding consumables and the stress involved. If the $t_{8/5}$ time associated with welding is too short, excessive hardening can occur in the HAZ. When the hydrogen in the weld is above a critical level the hardened zone can crack spontaneously under the influence of residual stress after the weld has cooled to near ambient temperature. Welding conditions may be selected to avoid cracking by ensuring that the HAZ cools sufficiently slowly, by control of weld run dimensions in relation to metal thickness, and if necessary, by applying preheat and controlling interpass temperature. Procedures for avoiding hydrogen cracking, as well as selecting cooling times through the transformation temperature range to avoid hardened and susceptible microstructures, may involve controlling cooling in the lower temperature part of the thermal cycle, typically from 300 °C to 100 °C, thereby beneficially influencing the evolution of hydrogen from the welded joint. In particular, this can be achieved by the application of a post heat on completion of welding simply by maintaining the preheat temperature.

The hydrogen content of the weld can be controlled by using hydrogen controlled welding processes and consumables, and also to some extent, by the application of post-heat as described above.

Similar considerations apply to hydrogen cracking in the weld metal where, although hardening will be on a reduced scale, actual hydrogen and stress levels are likely to be higher than in the heat affected zone. In general, welding procedures selected to avoid HAZ hydrogen cracking will also avoid cracking in the weld metal. However, under some conditions such as high restraint, low CE steels, thick sections or alloyed weld metal, weld metal hydrogen cracking can become the dominant mechanism.

The most effective assurance of avoiding hydrogen cracking is to reduce the hydrogen input to the weld metal from the welding consumables. The benefits resulting from a growing number of possibilities where no preheat temperature > 20 °C is required, can — as shown by examples in Table A.1 — be increased by using filler materials with lower hydrogen content.

Welding conditions for avoiding hydrogen cracking in carbon manganese steels have been drawn up in graphical form in Figure A.2 for the normal range of compositions, expressed as CE, covered by this part of ISO/TR 17671 and these conditions should be followed for all types of joint whenever practicable.

The conditions have been drawn up to take account of differences in behaviour between different steels of the same CE (making allowances for scatter in hardness) and of normal variations between ladle and product analysis. They are valid for the avoidance of both HAZ and weld metal cracking in the majority of welding situations (see also A.2.9).