TECHNICAL REPORT

ISO/TR 17671-3

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Welding — Recommendations for welding of metallic materials —

Part 3:
Arc welding of stainless steels

Soudage — Recommandations pour le soudage des matériaux métalliques —

Partie 3: Soudage à l'arc des aciers inoxydables

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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is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.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 17671-3 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*

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Introduction

This part of ISO/TR 17671 is being issued with several annexes in order that it may be extended to cover the different types of steel which will be produced to all the International steel standards for stainless steels.

When this part of ISO/TR 17671 is referenced for contractual purposes, the ordering authority should state the need for compliance with the document and such other annexes as are appropriate.

This part of ISO/TR 17671 gives general guidance for the satisfactory production and control of welding and details the possible detrimental phenomena that may occur with advice on methods by which they may be avoided. It is generally applicable to all stainless steels and is appropriate regardless of the type of fabrication involved, although the application standard may have additional requirements. Permissible design stresses in welds, methods of testing and acceptance levels are not included because they depend on the service conditions of fabrication. These details should be obtained from the design specification.

This part of ISO/TR 17671 contains additional details for fusion welding of stainless steels and should be read in conjunction with the general recommendations in ISO/TR 17671-1.

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Welding — Recommendations for welding of metallic materials —

Part 3:
Arc welding of stainless steels

1 Scope

This part of ISO/TR 17671 gives general recommendations for the fusion welding of stainless steels. Specific details relevant to austenitic, austenitic-ferritic, ferritic and martensitic stainless steels are given in annexes A to D.

2 References

ISO 3581, *Welding consumables — Covered electrodes for manual metal arc welding of stainless and heat-resisting steels — Classification*

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

ISO 8249, *Welding — Determination of Ferrite Number (FN) in austenic and duplex ferritic-austenitic Cr-Ni stainless steel weld metals*

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 14175, *Welding consumables — Shielding gases for arc welding and cutting*

ISO 14343, *Welding consumables — Wire electrodes, wires and rods for arc welding of stainless and heat resisting steels — Classification*

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

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

EN 10088-1:1995, *Stainless steels — Part 1: List of stainless steels*

EN 12073, *Welding consumables — Tubular cored electrodes for metal arc welding with or without a gas shield of stainless and heat resisting steels — Classification*

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3 Terms and definitions

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

3.1
passive layer
thin, transparent and tightly adherent film on the surface of stainless steels, which protects them from corrosive attack

3.2
stabilized steels
steels containing additions of strong carbide/nitride-forming elements (usually titanium or niobium), which limit the formation of chromium carbides/nitrides, allowing the stainless steel to retain its corrosion resistance, particularly around grain boundaries

3.3
non-stabilized steels
steels without the addition of strong carbide/nitride-forming elements (see 3.2)

3.4
ferrite number
FN
a number indicating magnetic attraction, relative to a series of reference samples and therefore, proportional to the ferro-magnetic phase content, approximately equal to ferrite (delta ferrite) content over the range 0 % to 10 % but more readily measured

[ISO 8249]

3.5
consumable insert
length of filler metal that is manufactured to conform to the shape and dimensions of the weld preparation and is melted to become an integral part of the joint during welding

3.6
proof strength
$R_{p0,2}$
tensile load which produces a plastic extension of 0,2 % of the original gauge length of the test specimen

4 Parent metal

This part of ISO/TR 17671 applies to stainless steels of the austenitic, ferritic, martensitic and austenitic/ferritic types, in accordance with groups 7 to 10 of ISO/TR 15608:2000.

5 Storage and handling

When storing, handling or fabricating stainless steel, the environment should be controlled to avoid permanent breakdown of the passive layer, which gives stainless steel its good corrosion resistance. Stainless steels should be protected from contamination and surface damage during all stages of storage, fabrication and transportation.

Contact between stainless steels and other materials, e.g. carbon steels, copper, paints, dyes and tapes, which cause a breakdown of the passive layer or other detrimental effects should be avoided. When contact is not avoidable, care should be taken that all residues are removed.

Racking for stainless steels should be strongly built and lined in a secure manner with materials that will not contaminate stainless steel, e.g. dry wood or stainless steel. Unlined or painted carbon steel racking should not be used. Lifting grabs should be made from or lined with a non-contaminating material.

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Welding fixtures, earth clamps or manipulators should be either manufactured from or lined with non-contaminating materials.

6 Welding consumables

Filler materials should be selected with regard to the parent metals and the particular application and should comply with the relevant standards.

Where consumable inserts are used they should correspond with the relevant filler metal composition.

7 Fabrication

7.1 General

Facilities for fabrication of stainless steels should be segregated from other works and kept free of all possible contaminating materials such as lead, zinc, copper, copper alloys or carbon steels, etc.

Forming tools should be cleaned thoroughly before use to avoid cross contamination. All lubricants used in the forming operations should be removed from the workpiece.

Only tools dedicated to stainless steel should be employed. This particularly applies to grinding wheels and wire brushes.

Welding heats up the parent metal and this causes formation of oxide films both on the weld metal and on the surrounding areas of the weld. These oxides as well as slags produced by covered electrodes, flux cored wires and submerged arc welding, should be removed if the weld is to be exposed to a corrosive medium or for other reasons (see clause 10).

When preparing fusion faces, oxidation, hardening and general contamination from thermal cutting processes should be eliminated by mechanically machining to a sufficient depth from the cut face. During shearing, cracking can occur. Thise may also require to be removed prior to welding.

Where cut edges do not form fusion faces, care should be taken to ensure that the shearing or thermal cutting does not adversely affect the performance of the fabrication.

Hard stamping should be avoided, but when it has to be used attention is drawn to the danger of it being applied in highly stressed or corrosive areas and the purchaser should give guidance as to the location of such marks. Indentations used for marking in radiographic examination should be subject to similar precautions.

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

7.2 Weld details

Welding details should be described in an appropriate Welding Procedure Specification (WPS) in accordance with ISO 9956-2.

Further details of weldability aspects are given in annexes A to D.

Acceptance criteria for misalignment of joints are given in ISO 5817. For certain applications (e.g. the welding of pipework) and welding processes, closer tolerances may be necessary.

Where run-on/run-off pieces are used these should be manufactured from a grade of stainless steel compatible with that used for the fabrication and should have a thickness and edge preparation similar to that used for the joint.

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The removal of run-on/run-off pieces should be performed by a method that does not adversely affect the properties of the parent metal and weld deposit. Inspection should be carried out to demonstrate that both the parent material and weld deposit are free from unacceptable imperfections.

Where the weld has to be made from one side only, it may be necessary to protect the root side from atmospheric contamination in order to maintain the corrosion resistance of the joint. The root run of such welds is generally made using the TIG or plasma welding process.

NOTE Pulse MIG/MAG-technique is also used.

7.3 Weld backing

Permanent backing should consist of a compatible grade of stainless steel and should not be used where there is a risk of crevice corrosion.

When it is not appropriate to use part of the structure as backing material, the material to be used should be as required by the design specification.

When using copper as a temporary backing material, a groove should be machined into the backing material in the fusion area. Care should be taken when welding as there is a risk of copper pick-up. This can be reduced by nickel or chromium plating of the copper backing material. When using high heat input, the copper backing may be water-cooled.

Backing material shall be free from contamination such as grease, moisture, oxide, etc.

Where temporary or permanent backing 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 obtained.

When it is necessary to prevent oxidation on the reverse side of a weld, purging using a suitable gas supply should be carried out. This is where a high purity gas or gas mixture, in accordance with ISO 14175, compatible with the parent and weld metal, is passed over the weld root. The purpose is to prevent contamination by the atmosphere, principally oxygen, which can lead to unacceptable imperfections in the weld and/or a reduction of corrosion resistance.

Where purging of the root area is to be carried out, the duration of purging prior to welding should be sufficient to ensure that the level of root oxidation is as required by the design specification. The prepurge time will depend principally on gas flow rate, volume to be purged and, to a lesser extent, purging gas density and injection point.

Where maximum permissible oxygen levels are specified in the contract, it will be necessary to use an oxygen analyser of suitable sensitivity to measure the oxygen content of the exit gas. As a guideline, it is suggested that ten volume changes be made before commencing welding.

Gas purging should be maintained for sufficient duration to ensure that the finished weld underside surface oxidation level is contractually acceptable.

8 Quality requirements of welds

Welded joints should be free from imperfections that would impair the service performance of the construction. Acceptance levels should be in accordance with the application standard where it exists. If no application standard exists, acceptance levels should be based on ISO 5817.

Special quality requirements for stainless steels may be taken into account, such as appearance and corrosion resistance, and shall be specified in the contract.

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9 Distortion

Distortion in a weldment results from non-uniform expansion and contraction of weld metal and adjacent parent metal during welding. In austenitic stainless steel, this phenomenon is much more pronounced than in unalloyed steel due to a larger expansion coefficient and a lower thermal conductivity.

There are various practical ways of minimizing distortion such as:

— minimizing the weld metal volume;

— balanced (double sided) joint welding;

— reduced heat input;

— reduced numbers of weld layers;

— backstep welding;

— preset of the parts to be welded;

— jigs and mechanical restraints;

— tack welding;

— heat sinks.

Care should be taken that the methods chosen do not have a deleterious effect on the properties of the welds and the overall structure.

10 Post-weld cleaning

10.1 General

The corrosion resistance of stainless steel weldments is significantly affected by their surface condition. The degree of post-weld cleaning necessary depends upon the weld quality requirements and should be as required by the design specification.

Post-weld cleaning can be carried out by several processes, either separately or in combination. See 10.2 to 10.6.

10.2 Brushing

Dedicated wire brushes made with stainless steel bristles or other compatible material should be used. This technique cannot be used, in general, to remove adherent contaminants. Care should be taken when using mechanical rotary brushing as this may deform the surface giving microcrevices which will reduce corrosion resistance. It may be necessary to follow brushing with a pickling operation (see 10.5).

10.3 Shot blasting

This technique is used for the removal of adherant contaminants and also to give residual compressive stresses in the surface. Recommended blasting media include glass and stainless steel shot. These should be free from iron or carbon steel contamination. It is also known as peening.

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10.4 Grinding

Dedicated iron free grinding discs, belts or wheels should be used. Excessive grinding should be avoided to prevent damage to the surface and thinning of the parent metal. The technique is used to remove heavy surface contaminants and to blend the weld smoothly into the parent metal.

10.5 Pickling

Pickling removes surface oxides or surface layers of the steel by chemical reaction. An acid medium is used whose composition is dependent on the type of steel, pickling temperature and time. Careful removal of all pickling products needs to be carried out.

10.6 Electro-polishing

This is used, generally, on non-stabilized stainless steels in order to give a smooth surface for optimum corrosion resistance.

For optimum corrosion resistance, the most effective cleaning processes are pickling and electro-polishing, followed by a natural or induced passivation treatment.

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Annex A

Welding of austenitic stainless steels

A.1 General

A.1.1 Chemical composition

The chemical compositions of typical austenitic stainless steels are listed in EN 10088-1. These steels generally contain a minimum of 16,5 % chromium, with sufficient nickel and/or manganese, carbon and nitrogen to produce an austenitic microstructure. They may also contain additions of other elements such as molybdenum, nitrogen, titanium, niobium, copper, silicon or sulfur to improve specific properties such as corrosion resistance, oxidation resistance, or machinability, etc.

A.1.2 Microstructure

The microstructures of austenitic stainless steels are governed by the balance of ferrite- and austenite-stabilizing elements. The principal ferrite-stabilizing elements are chromium, molybdenum and silicon, while the principal austenite stabilizing elements are nickel, manganese, carbon and nitrogen. The structure which will form in the weld metal may be predicted from the balance of ferrite- and austenite-stabilizing elements, using e.g. a Schaeffler, DeLong, W.R.C. or Espy diagram.

Austenitic stainless steels consist of an austenite matrix which, in certain grades, may contain small quantities of delta ferrite, the amount of ferrite increasing during welding without the addition of a filler metal. Other grades are fully austenitic and contain no ferrite, even after welding.

Austenitic stainless steels are usually supplied in the solution annealed condition, which involves heating to approximately 1 050°C, or higher, followed by rapid cooling to room temperature. Annealing results in softening of the steel and minimizes the delta ferrite content, so that even steels which form delta ferrite during welding will generally contain virtually no ferrite in the annealed condition.

A.1.3 Types of austenitic stainless steel

A.1.3.1 Standard austenitic stainless steels

Most of the standard austenitic stainless steels are not fully austenitic but may form a small amount of delta ferrite after welding without the addition of a filler metal. The standard stainless steels in this category are still referred to as austenitic stainless steels, even when a small amount of ferrite is present, e.g. grades 1.4301, 1.4401 and 1.4436 of EN 10088-1:1995.

The carbon content of the standard austenitic stainless steels is normally less than 0,06 %.

In order to minimize the formation of chromium carbides during welding, low carbon ($<$ 0,03 %) versions of many standard grades are produced, resulting in improved corrosion resistance in certain environments, e.g. grades 1.4307, 1.4404 and 1.4432 of EN 10088-1:1995.

Similar improvements in the corrosion resistance of standard grades may be obtained through the additions of either titanium, or niobium/tantalum, which combine with carbon, preventing the formation of chromium carbides during welding. These grades are referred to as 'stabilized' austenitic stainless steel, e.g. grades 1.4541 and 1.4550 of EN 10088-1:1995.

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A.1.3.2 Fully austenitic stainless steels

The compositional balance of these steels is adjusted to obtain specific properties such as low magnetic permeability (non magnetic), increased corrosion resistance or high temperature creep/oxidation resistance, resulting in a fully austenitic structure at all times, e.g. grade 1.4335 of EN 10088-1:1995. Due to their high toughness at low temperatures, fully austenitic steels may also be used for cryogenic applications.

The risk of solidification cracking during welding is increased in these steels.

Superaustenitic and enhanced corrosion resistant grades belong to the fully austenitic family. These steels contain increased chromium contents and additions of other elements, including molybdenum and nitrogen for increased resistance to pitting and crevice corrosion, and copper for enhanced acid corrosion resistance. An increased nickel content is added to stabilize a fully austenitic structure. These steels possess extremely high corrosion resistance and require particular care during welding in order to maintain the high corrosion resistance of the parent metal, e.g. grades 1.4539 and 1.4547 of EN 10088-1:1995.

A.1.3.3 Other variations with improved properties

Other austenitic stainless steels exist in which the chemical composition has been adjusted to improve specific properties. Depending on the actual chemical composition, each of these grades belongs in one of the above mentioned categories (A.1.3.1 and A.1.3.2) and should be welded with similar precautions.

a) **Nitrogen alloyed austenitic steels with high proof strength**. These steels contain small additions of nitrogen (up to 0,45 %), resulting in an increase in $R_{p0,2}$. The nitrogen may be added to both normal and low carbon grades of stainless steel. Nitrogen is an austenite-stabilizing element and may result in a reduction in delta ferrite content during welding.

b) **Heat resistant austenitic steels**. Steels for use at high temperatures may contain increased chromium and/or silicon contents in order to provide enhanced oxidation resistance. Additions of molybdenum, nitrogen, aluminium, carbon, rare earth elements, titanium and/or niobium may also be made to increase high temperature properties.

c) **Austenitic steels with improved machinability**. Improved machining grades contain increased sulfur contents (up to 0,35 %) and/or additions of other elements such as calcium or selenium and consequently generally exhibit reduced weldability and corrosion resistance.

A.2 Welding aspects

A.2.1 Welding details

All of the common welding processes listed in ISO/TR 17671-1 are suitable for welding austenitic stainless steels.

Heat input should be low in order to reduce the risk of distortion, hot cracking and sensitization or intermetallic precipitation.

Preheat should be avoided when welding austenitic stainless steels as the additional heat input will increase the risk of distortion, hot cracking, sensitization and intermetallic precipitation.

Joint preparations for welding are similar to those used for carbon steels, although different angles and root gaps may be used, e.g. nitrogen alloyed steels may require wider joint preparations.

When welding thin sheet and plate, a weld may be possible by fusing the joint edges together, without filler metal.

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A.2.2 Welding consumables

All consumables should be selected in accordance with the manufacturer's/supplier's recommendations.

Where required, filler metals/rods should be selected in accordance with ISO 3581, ISO 14343 or EN 12073.

Consumables for standard austenitic stainless steels are generally designed to result in a ferrite content of between 3 FN and 15 FN in the as-deposited fusion zone, for enhanced resistance to hot cracking.

Schaeffler, De Long, W.R.C. or Espy diagrams may be used to determine if the consumable will provide the correct ferrite content, taking dilution effects into account.

Fully austenitic stainless steels are non magnetic. The presence of delta ferrite in the austenite results in a small degree of magnetism and this characteristic is used to measure the proportion of ferrite in the weld metal, after welding.

The chemical composition of the welding consumable is usually slightly over-alloyed with respect to the parent metal, to optimize corrosion resistance by compensating for alloy losses, segregation effects, inclusions and surface imperfections inherent in the weld metal.

Fully austenitic stainless steels require the use of approximately similar or slightly over-alloyed consumables and are susceptible to hot cracking. The precautions indicated in A.3.1 should, therefore, be followed. The consumables may contain increased manganese contents, to minimize the risk of hot cracking.

Nickel-based consumables are generally used for superaustenitic steels.

Shielding gases for TIG welding are usually argon, argon-hydrogen, argon-helium or combinations of these gases, in accordance with ISO 14175.

The addition of either hydrogen or helium to argon (in accordance with ISO 14175) will often allow higher welding speeds, while the reducing nature of hydrogen-bearing gases can also result in cleaner welds.

Shielding gases for MIG/MAG welding of austenitic stainless steels should be selected in accordance with ISO 14175, as a wide choice is now available.

A.3 Consequences of welding

A.3.1 Cracking

Due to their inherently high ductility and toughness, austenitic stainless steels rarely suffer from “cold” cracking after welding.

Some austenitic stainless steel weldments, however, can be susceptible to hot cracking, which includes cracking during solidification (solidification cracks) and cracking in the heat affected zone of the weld metal or parent metal (liquation cracks). This cracking is associated with impurity elements, such as sulfur and phosphorous, segregating to interdendritic regions and grain boundaries to form low melting point phases. Contraction forces during cooling of the weld metal can pull the liquid films apart to produce a crack.

Solidification mode has a great influence on resistance to hot cracking. Austenitic stainless steels can solidify as ferrite, austenite or a mixture of these phases, depending on composition. Ferritic solidification results in much lower sensitivity to hot cracking. The chemical composition of the standard austenitic stainless steel, therefore, is generally balanced to provide ferritic solidification, resulting in a ferrite content of $\geqslant$ 3 FN and a reduced risk of solidification cracking (see ISO 8249 for measurement of ferrite content).

Hot cracking also depends on welding conditions. A high travel speed produces teardrop-shaped weld pools, encouraging centreline segregation of impurity elements and increasing the risk of cracking. A balance between the current and travel speed is necessary to obtain the optimum welding conditions.

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Further recommendations for avoiding hot cracking include the following.

a) For standard austenitic stainless steels, select consumables to give a ferrite content of between 3 FN and 15 FN in the weld deposit.

b) For fully austenitic stainless steels, select consumables with low impurity levels and increased manganese contents.

c) Ensure optimum cleanliness.

d) Reduce restraint on the joint.

e) Use low heat inputs and avoid wide weld pools.

f) Reduce interpass temperature (150 °C maximum).

g) Reduce travel speed.

h) The width to depth ratio of the weld pool should be between approximately 1 and 1,5.

Fully austenitic stainless steels are more susceptible to solidification cracking, due to their solidification mode. When welding these steels, therefore, it is necessary to take as many of the above precautions as possible with the exception of a).

A.3.2 Mechanical properties

The proof and tensile strength of welds in austenitic stainless steels are generally similar to, or greater than, those of the parent metal. Ductility may be slightly reduced but remains excellent. Post-weld heat treatment (PWHT), therefore, is not usually necessary.

Weld ductility and toughness may be impaired if significant amounts of intermetallic precipitates such as sigma and chi phase are formed. This usually occurs only in steels with a high chromium, molybdenum and silicon content, when high heat inputs are used. High heat inputs, therefore, should be avoided with the more highly alloyed austenitic stainless steels.

A.3.3 Corrosion resistance

A.3.3.1 Sensitization or weld decay

Good corrosion resistance depends on a uniform distribution of the elements chromium and molybdenum in the parent and weld metal. Any sensitization by carbides and nitrides, or precipitation of intermetallic phases, such as sigma, which could locally result in chromium and/or molybdenum depletion, should be avoided. The risk of sensitization is minimized by using low carbon grades ($\leqslant$ 0,030 %) or by using stabilized (containing titanium, niobium/tantalum) steels and consumables.

Contamination of the weld and heat affected zone (HAZ) should be avoided, to eliminate the risk of carbon and nitrogen pick-up. Shielding gases containing more than 2,5 % CO_2 should, therefore, be avoided, unless specifically recommended by the consumable manufacturer/supplier.

To reduce the risk of intermetallic precipitation during welding, the heat input and interpass temperature should be kept low.

A.3.3.2 Stress corrosion

Stress corrosion cracking can occur in austenitic stainless steels when they are exposed to combinations of adverse conditions, including certain aggressive media (such as halide solutions), elevated temperatures and applied tensile stress. The residual stresses from welding or grinding can often be sufficient to cause this form of attack, if the

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environmental criteria are also unfavourable. It is advisable, therefore, to ensure that residual stresses are minimized in fabrications which may be susceptible to this form of attack.

Resistance to stress corrosion may be increased significantly by using ferritic or duplex grades and superaustenitic steels with high nickel contents (standard ferritic stainless steel grades will, however, exhibit reduced resistance to general corrosion).

A.3.4 Distortion

Due to their increased thermal expansion and reduced thermal conductivity, compared to carbon steels, austenitic stainless steels are significantly more susceptible to distortion than carbon steels or other stainless steels. Recommendations for minimizing distortion are given in clause 9.

A.4 Post-weld treatment

A.4.1 Heat treatment

Post-weld heat treatment (PWHT) is not generally necessary for austenitic stainless steels. Heat treatment may sometimes be necessary, however, for stress-relief after cold deformation, for minimization of ferrite content or to minimize segregation/precipitation for optimum corrosion resistance. Such treatments generally require full solution annealing and therefore require careful consideration due to the risk of distortion, sagging and oxidation. Where full solution annealing cannot be carried out, low temperature stress relief at about 450 °C may be of benefit in relieving residual stresses and minimizing distortion.

A.4.2 Cleaning

To restore the corrosion resistance of the weldment, it is necessary to remove any surface contamination produced by the welding process.

Recommendations for the post-weld cleaning are given in clause 10.

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Annex B

Welding of ferritic stainless steels

B.1 General

B.1.1 Chemical composition

Ferritic stainless steels in accordance with EN 10088-1 generally contain between 10,5 % and 30 % chromium and up to 0,08 % carbon. Some types also contain one or more of the following elements: up to 4,5 % molybdenum; 1,6 % nickel; 2,1 % aluminium and titanium, niobium/tantalum or zirconium for stabilization. In certain grades the levels of carbon and nitrogen are kept very low (ELI-ferritics).

B.1.2 Microstructure

Depending on the ratio of ferrite- and austenite-forming elements, the microstructure of these steels consists of ferrite (fully ferritic) or of ferrite with amounts of martensite (semi-ferritic). Detailed information will be given by the supplier or the manufacturer of the steel.

The fully ferritic structure is susceptible to grain growth at temperatures above about 950 °C. This results in decreased toughness. Refining by heat treatment is not possible.

The grain growth is less pronounced in stabilized ferritic stainless steels and least pronounced in semi-ferritic stainless steels. The extent of the grain growth depends on the highest temperature, on the time at temperature and on the number of welding runs. Therefore welded parts of fully ferritic stainless steels provide adequate service only for a thin wall thickness (approximately 2,5 mm maximum).

Welds in thick section semi-ferritic stainless steels show improved toughness over the fully ferritic grades. Even when cooled rapidly from welding temperatures chromium carbides precipitate in the parent metal and the matching weld metal. These precipitates reduce the ductility and the resistance to intergranular corrosion by local chromium depletion. This depletion can be avoided, if the parent metal and the matching weld metal have a very low carbon content or preferably if stabilized by titanium, niobium/tantalum or zirconium.

Intermetallic precipitates, e.g. sigma phase, can form in steels with (chromium + molybdenum) greater than approximately 22 % in the temperature range of about 550 °C to 850 °C, leading to room-temperature embrittlement and in some cases reduced corrosion resistance. By heating in the range of 900 °C to 1 000 °C and subsequent rapid cooling to room temperature, the sigma phase can be brought into solution.

475 °C-embrittlement may occur in steels with chromium greater than 15 % in the temperature range of about 400 °C to 450 °C, giving a loss of ductility. The embrittlement can be removed by heating to approximately 540 °C and subsequent rapid cooling to room temperature.

B.2 Welding aspects

B.2.1 Welding details

Ferritic stainless steels can be welded using manual metal arc welding [MMA welding (111)], metal-arc inert gas welding [MIG welding (131)], metal-arc active gas welding [MAG welding (135)], tungsten inert gas welding [TIG welding (141)] and plasma arc welding (15).

Other welding processes, e.g. electron beam welding (51), laser welding (52), high-frequency resistance welding (291), may be used by agreement.

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Ferritic stainless steels are susceptible to excessive grain growth. Therefore welding heat input should be kept low, e.g. small weld pool, high travel speeds.

Preheating at between 200 °C and 300 °C may be used for semi-ferritic grades with a thickness over 3 mm. Interpass temperatures should be in the same range.

The pick-up of carbon and nitrogen during welding should be kept as low as possible, e.g. clean weld area, short arc length.

B.2.2 Welding consumables

Austenitic welding consumables are preferred because of the higher ductility of the austenitic weld metal, compared with matching compositions of the parent metal. Considering corrosion resistance, the chromium content of the weld deposit should not be less than that of the parent metal. If there is a danger of sulfur pick-up during service, the layer that is in contact with this environment should be welded with a ferritic stainless or ferritic-austenitic stainless consumable.

Ferritic stainless consumables are also chosen where similar thermal expansion, similar surface colour of welds or nickel-free welds are required.

TIG welding can be carried out either with or without filler metal.

Covered electrodes should be rebaked before welding, if necessary, in accordance with the manufacturer's/supplier's recommendations.

Shielding gases should be argon-based mixtures, e.g. M 13 in accordance with ISO 14175, and not containing CO_2 , hydrogen and/or nitrogen.

B.3 Consequences of welding

B.3.1 Cracking

Hot cracking in ferritic stainless steels is not normally a problem.

Weldments in these steels may be susceptible to the following:

a) cold cracking due to low toughness. In sections over 3 mm thickness (semi-ferritic), the weld zone may be preheated in the range 200 °C to 300 °C and conditions of high restraint should be avoided;

b) hydrogen embrittlement (hydrogen-induced cracking) should be avoided, therefore care should be taken to keep the hydrogen content as low as possible.

B.3.2 Mechanical properties

The proof stress and tensile strength of the weld metal of austenitic and ferritic consumables should match the requirements of the parent metal. Semi-ferritic stainless steels of low ductility shall be preheated in the range 200 °C to 300 °C prior to cold forming.

B.3.3 Corrosion resistance

Ferritic stainless steels suffer from intergranular corrosion, unless the chromium-depletion is avoided by extremely low contents of carbon and nitrogen, by stabilization (using titanium, niobium/tantalum or zirconium) or by annealing at temperatures between 750 °C and 800 °C. Ferritic stainless steels with chromium in the lower range and without nickel exhibit a weaker passive film in many chemical agents. For less aggressive conditions their corrosion resistance may be sufficient.

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B.3.4 Distortion

Ferritic stainless steels have a higher thermal conductivity and a lower thermal expansion coefficient than the austenitic stainless steels, hence distortion problems are not as pronounced.

B.4 Post-weld treatment

B.4.1 Heat treatment

Annealing after welding in the range 700 °C to 800 °C generally improves the ductility of HAZ and matching weld metals and reduces residual stresses. Such treatment will also restore the intergranular corrosion resistance of non-stabilized ferritic steels.

B.4.2 Finishing

To restore the corrosion resistance of the weldment, it is necessary to remove any surface contaminations produced by the welding process.

Recommendations for post-weld cleaning are given in clause 10.

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Annex C

Welding of austenitic-ferritic stainless steels

C.1 General

Austenitic-ferritic stainless steels, generally termed duplex stainless steels, are employed for their strength and corrosion resistance. They are commonly used in the temperature range of – 50 °C to + 250 °C.

C.1.1 Chemical composition

Duplex steels in accordance with EN 10088-1 generally contain 21 % to 28 % chromium, 3,5 % to 8,0 % nickel, 0,1 % to 4,5 % molybdenum and 0,05 % to 0,35 % nitrogen. Some of them also contain copper and tungsten.

C.1.2 Microstructure

Duplex stainless steels consist of a ferritic matrix with approximately 45 % to 60 % austenite. This structure is achieved by solution annealing at around 1 020 °C to 1 100 °C, depending on grade, followed by rapid cooling.

C.1.3 Types of austenitic-ferritic stainless steel

C.1.3.1 Low alloyed

The low alloyed duplex stainless steels, e.g. grade 1.4362 of EN 10088-1:1995, are characterized by a very low molybdenum content. Their main application area is to replace common austenitic stainless steels where these may suffer from stress corrosion cracking.

C.1.3.2 Medium alloyed

The most commonly used duplex stainless steels, e.g. grade 1.4462 of EN 10088-1:1995, are the molybdenum-containing medium alloyed grades. These are general purpose steels used mainly for chemical, petrochemical and offshore applications.

C.1.3.3 High alloyed

The high alloyed duplex stainless steels, e.g. grade 1.4410 of EN 10088-1:1995, contain higher chromium, molybdenum and nitrogen contents, compared to the medium alloyed duplex stainless steels, and are therefore used in severe corrosive environments.

C.2 Welding aspects

C.2.1 Welding details

The weldability of duplex stainless steels has been improved by optimization of the austenite-ferrite balance and by the introduction of increased nitrogen contents. The risk of detrimental grain growth or excessive amounts of ferrite in the HAZ after welding is low.

All of the common arc welding processes listed in ISO/TR 17671-1 are suitable for welding duplex stainless steels. Welding processes that are normally carried out without the addition of filler metal or that give extremely rapid cooling, e.g. plasma arc, laser beam, electron beam and resistance welding, can only be used if special precautions are taken.

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Welding without filler metal is not recommended unless the joint is solution annealed after welding followed by rapid cooling to room temperature. Welding without filler metal and without post-weld heat treatment, can provide satisfactory properties if nitrogen-containing shielding gas is used to improve austenite reformation.

Joint preparation should be in accordance with ISO 9692-1 but for V-joints and double V-joints, it is sometimes recommended to use a wider angle than for austenitic stainless steels in order to get good penetration. When welding the root pass with TIG or MIG/MAG, it is recommended to use a wider gap than for austenitic steels, for the same reason.

Due to the high strength of duplex stainless steels, the distance between tack welds should be small.

Preheat is not necessary but can be used to maximum of 100 °C to remove moisture from the surface.

The heat input for duplex stainless steels has to be within certain limits. Too low a heat input leads to a high cooling rate which may result in high ferrite levels. Too high a heat input can result in precipitation of intermetallic phases. The low- and medium-alloyed types are normally welded with a heat input of 0,5 kJ/mm to 2,5 kJ/mm and an interpass temperature less than 250 °C. For the high-alloyed types the heat input range is normally limited to 0,2 kJ/mm to 1,5 kJ/mm and a maximum interpass temperature in the range of 100 °C to 150 °C. These figures give general recommendations only. It is also necessary to take into account the effect of the welding process and work piece thickness.

C.2.2 Welding consumables

To obtain the correct weld metal microstructure a filler metal overalloyed with nickel should be used. With such compositions the effect of both rapid cooling after welding and high dilution of the parent metal in the root run can be overcome.

For the low- and medium-alloyed types, in aggressive corrosive environments a duplex filler metal overalloyed with chromium, molybdenum and nitrogen can be used, e.g. a high alloyed duplex filler for a medium alloyed duplex stainless steel.

All shielding gases should be selected in accordance with ISO 14175.

Recommended shielding gases for TIG and plasma arc welding are argon, argon-helium or argon with up to 3 % nitrogen. Hydrogen-bearing shielding gases should be avoided.

For MAG welding standard gases such as argon with up to 2,5 % carbon dioxide, argon-helium-oxygen mixtures, argon-helium-carbon dioxide mixtures or gases with the addition of up to 3 % nitrogen can be used.

For flux cored wire metal arc welding reference should be made to the manufacturer’s recommendations for further information on shielding gases.

Recommended backing gases where required, should be argon, argon-nitrogen mixtures or pure nitrogen, or in special cases nitrogen/hydrogen mixtures.

For submerged arc welding rutile fluxes normally give low impact values. A more basic flux improves impact toughness. A fully basic flux, however, can lead to problems with slag removal.

C.3 Consequences of welding

C.3.1 General

Duplex stainless steels with increased contents of chromium, molybdenum and tungsten result in higher susceptibility to precipitation of intermetallic phases which may have detrimental effects on mechanical properties and corrosion

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C.3.2 Cracking

Duplex stainless steels have a low sensitivity to hot cracking, due to their ferritic solidification mode.

Hydrogen in duplex weld metals can be responsible for delayed crack formation where the weld metal has a very high ferrite level of > 110 FN (= approximately 75 % ferrite) and a high hydrogen level combined with a high degree of restraint.

C.3.3 Mechanical properties

The strength of a duplex stainless steel weld metal always exceeds the minimum strength of the corresponding parent metal.

For duplex all-weld metals, the elongation values are often around 25 %.

For medium- and high-alloyed duplex weldments used in hydrogen sulfide-containing media, there is normally a demand on maximum hardness of 28 HRC for medium alloyed and 32 HRC for high alloyed duplex stainless steels.

For most applications these maximum hardness restrictions can be satisfied. The highest hardness is measured in the root area in thick single-sided joints, due to the strain imparted by subsequent weld runs.

The impact toughness in welds is lower than in the parent metal and depends mainly on the ferrite level, welding process and consumables used.

C.3.4 Corrosion resistance

The corrosion resistance of duplex stainless steels is related to their microstructure and chemical composition. They are generally used for their good pitting and stress corrosion cracking resistance.

It is important to use parent and filler metals which give a controlled and acceptable austenite-ferrite balance both in the HAZ and in the weld metal. Acceptance properties are generally achieved where ferrite contents of 30 FN to 100 FN are obtained.

Nitrogen is an essential alloying element for maximum corrosion resistance. Nitrogen loss can occur during TIG and MIG/MAG welding. Welds made using covered electrodes and submerged arc welding, do not tend to show this loss of nitrogen.

C.3.5 Distortion

Distortion during welding of duplex stainless steels is lower than that of austenitic stainless steels. However, the duplex grades are more difficult to straighten after welding due to their high proof strength.

C.3.6 Porosity

Duplex stainless steels with high nitrogen contents (> 0,20 %) are more prone to the formation of porosity during welding than are standard austenitic stainless steels.

The possibility of porosity is increased when welding in the overhead position. In order to decrease this problem, thin runs should be deposited and excessive arc lengths avoided.

In order to increase pitting resistance, nitrogen can be added to the shielding gas. Application should be restricted to appropriate regions of the joint (root and capping layer) to avoid excessive weld metal nitrogen build up and porosity. Excessive shielding gas flow rates will also increase the risk of porosity.

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C.4 Post-weld treatment

C.4.1 Heat treatment

Post-weld heat treatment (PWHT) is normally not necessary for duplex stainless steels.

If post-weld solution annealing is to be performed, the temperature should generally be 30 °C to 40 °C higher than the solution annealing temperature recommended for the parent metal to dissolve intermetallic phases. This should be followed by rapid quenching to room temperature.

C.4.2 Cleaning

The same technique can be used for duplex stainless steels as detailed in clause 10.

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Annex D

Welding of martensitic and martensitic-austenitic stainless steels

D.1 General

D.1.1 Chemical composition

Martensitic stainless steels, in accordance with EN 10088-1, generally contain between 13 % and 17 % chromium with up to 4 % nickel and up to 1,0 % carbon. They can be divided into three different types according to their chemical composition.

D.1.2 Types of martensitic and martensitic-austenitic stainless steel

D.1.2.1 Martensitic stainless steels

The martensitic stainless grades are fully martensitic at room temperature and are therefore very hard and brittle. Tempering is required to give some ductility and toughness, with a consequential reduction of tensile strength.

D.1.2.2 Martensitic-austenitic stainless steels

Grades with less than 0,1 % carbon have a structure consisting of 5 % to 25 % austenite in a martensitic matrix. As a result, lower strength and hardness and improved ductility are achieved.

D.1.2.3 Precipitation hardening martensitic stainless steels

The martensitic grades can be strengthened by nearly 50 % by the addition of copper, titanium, niobium, aluminium and molybdenum to give precipitation hardening, it is usual in these steels to reduce the carbon content to below 0,1 %. The steels therefore consist of a tempered martensitic matrix with precipitates usually achieved by a double heat treatment after quenching. Various strengths can be achieved by altering the ageing conditions.

D.2 Welding aspects

Generally tungsten inert gas welding [TIG welding (141)] and manual metal-arc welding [MMA welding (111)] are the only processes used. However, for certain specialized applications, plasma arc welding (15), metal-arc inert gas welding [MIG welding (131)]/metal-arc active gas welding [MAG welding (135)], submerged arc welding (12) and other processes may be used.

All grades may be welded using austenitic consumables or matching consumables. If austenitic consumables are used, the weld metal will undermatch the parent metal in strength.

Normal heat inputs (e.g. 0,5 kJ/mm to 1,5 kJ/mm for manual metal-arc welding) should be used and excessively high or excessively low heat inputs should be avoided.

a) **Martensitic stainless steels**

Preheat is required for steel grades with greater than 0,1 % carbon and typically preheats in the range 200 °C to 300 °C should be used depending on joint geometry and stress levels. Higher preheats may be required for thick sections and highly stressed joints. High carbon contents make the steel air-hardenable. For carbon contents up to 0,2 %, welding may be followed by slow cooling. Above 0,2 % carbon a post-weld anneal is required. If the weld is to be hardened and tempered immediately after welding, then post-weld annealing can be omitted.

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b) **Martensitic-austenitic stainless steels**

Preheat is not required for thin sections ⩽ 8 mm, for thicker sections preheating in the range 100 °C to 200 °C may be required. Matching filler metals are often used.

c) **Precipitation hardening martensitic stainless steels**

The precipitation hardening martensitic stainless grades are normally welded using matching consumables. Austenitic consumables may be used, but full strength cannot be achieved. When using austenitic consumables preheating is not required, due to the generally low carbon contents (less than 0,1 %), and the fact that full strength is not achieved by the transformation to martensitic during cooling.

D.3 Consequences of welding

D.3.1 Cracking

Hot cracking in martensitic stainless steels is not normally a problem, however, cleanliness is still important.

Cold cracking susceptibility is a function of hydrogen level, stress, cooling rate, chemical composition and for martensitic-austenitic grades, the percentage of martensite present. Cracking sensitivity increases with increasing carbon content. Low carbon grades, i.e. the martensitic-austenitic grades are less sensitive to cold cracking and hence may be welded without preheat.

Preheating can be applied to avoid cold cracking and may need to be supplemented by post-weld annealing, depending on the alloy.

The use of austenitic consumables significantly reduces the hydrogen cracking risk, due to the higher hydrogen solubility of the austenite.

D.3.2 Mechanical properties

During welding, quenching and tempering effects occur in the weld and HAZ, giving a variety of properties. In the HAZ and in martensitic weld metals, the as-welded structures will be largely untempered martensite, with a few small areas of tempering from subsequent weld runs. For the martensitic-austenitic grades some austenite is retained giving lower strength than the martensitic grades.

D.3.3 Corrosion resistance

Corrosion resistance is generally lower than that of the austenitic grades. The martensitic grades suffer from crevice and pitting corrosion, although this is improved for those grades with added molybdenum. These steels are not usually used in highly corrosive environments but are often selected for wear and cavitation resistance. The corrosion resistance of the martensitic-austenitic grades is improved over the martensitic grades.

D.3.4 Distortion

Martensitic stainless steels have generally higher thermal conductivity and a lower expansion coefficient than the austenitics, hence distortion problems are not as pronounced.

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D.4 Post-weld treatment

D.4.1 Heat treatment

Martensitic stainless grades, if welded with austenitic consumables, do not normally require PWHT. If matching consumables are used, then post-weld heat treatment is required to obtain optimum properties. When required it should be done according to the manufacturer's recommendations for the parent metal.

Martensitic-austenitic stainless grades do not generally require PWHT to develop optimum mechanical properties. Precipitation hardening grades are normally welded in the solution treated condition. If a matching filler is used, heat treatment is normally a solution treatment and quenching process followed by age hardening. This should be carried out in accordance with the manufacturer's/supplier's recommendations.

D.4.2 Cleaning

Pickling of precipitation hardened or high carbon content steels is not recommended due to the difficulty of achieving a good surface finish.

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