OPERATIONAL GUIDELINES AND CODE OF PRACTICE FOR STAINLESS STEEL PRODUCTS IN DRINKING WATER SUPPLY

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Working Party Members:

Duncan Munro (Chairman)	British Stainless Steel Association
Chris Baxter	AvestaPolarit Ltd
Tony Biddle	Steel Construction Institute
Doug Chamberlain	AvestaPolarit Ltd
Roger Crookes	Stainless Steel Advisory Service
Peter Cutler	Nickel Development Institute
Dave Garrett	AvestaPolarit Ltd
David Jordan	Nickel Development Institute
Tony Newson	AvestaPolarit Ltd
Carol Powell	Nickel Development Institute
Brian Tandy	Steel Construction Institute

Consultees from the water industry:

Peter Claye/John Greenwood	Thames Water Engineering Ltd
Mark Froggatt	Biwater Treatment Ltd
Mukund Kothari	Degremont UK Ltd
Ivan Lowe	Purac Ltd
David Wickett	OTV Birwelco Ltd
John Spolverino	Bender Forest
Ray Bruni	Whitefield Fabrications
Graham Newman	Pruce Newman Pipework
Tom Smith	Jerome Engineering
David Astley	Viking Johnson Fabricators
Dominic Cutts/Nigel Higginbottom	FSD Golding Pipework
Peter Lee	Fletcher Engineering
Dick Wakelin	Lancashire Fittings
Sid Tempest	Tempest-Stansfield Associates
Michael Musgrave	Brockington & Scott
Steve Lamb	Consultancy Resources Corporation

Les Boulton Les Boulton & Associates Ltd

Assistance from the Drinking Water Inspectorate:

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PREFACE

The requirements of the OGCP have legal status (i.e. under the Water Supply/Quality Regulations 25/31) once individual stainless steel materials and products have received Regulation 25 (1)(a) approval and/or Regulation 31 approval as the clauses of this latter Regulation are implemented (Regulation 31 is scheduled to come into force on 1st January 2004). The document also contains recommendations and suggestions that are not such legal requirements. Such Regulation 25/31 legal requirements are identified by the use of the imperative term ***shall*** in this OGCP and are intended for use in model Specifications of Contract (which are separate documents[1] distinct from, but based on this OGCP). The term ***shall*** in this OGCP also embraces other, legal and non-legal requirements, such as compliance with Health & Safety regulations and UK and international standards. Such compliance is clear from the context of the requirement.

Recommendations and suggestions are identified by the informative terms "should", "may" etc. The term "should" means "ought to" or "It is recommended that…", but is not an imperative requirement.

The OGCP also provides a background to the nature and properties of stainless steel and other additional information that will assist water industry engineers to specify, install and operate stainless steel materials and products, together with more detailed references.

Although all care has been taken to ensure that the information contained herein is accurate, the contributors assume no responsibility for any errors or misinterpretations of such data and/or information or any loss or damage arising from or related to their use.

[1] A model Specification of Contract is currently under development by the stainless steel industry and other relevant parties.

CONTENTS

INTRODUCTION

This OPERATIONAL GUIDELINES AND CODE OF PRACTICE (OGCP) FOR STAINLESS STEEL PRODUCTS IN DRINKING WATER SUPPLY document formed part of an application through the Drinking Water Inspectorate (DWI) Committee on Products and Processes (CPP), to the (then) Secretary of State for the Environment, Transport and the Regions (now Environment, Food and Rural Affairs), The Scottish Parliament, The National Assembly for Wales and the Northern Ireland Assembly for authorisation of the use of stainless steel materials and products, and was originally submitted to DWI in April 2001. These authorisations were required at the time of submission under Regulation 25 (1)(a) of the Water Supply (Water Quality) Regulations 1989 and its equivalents in Scotland and Northern Ireland, and subsequently, Regulation 31 of the Water Supply (Water Quality) Regulations 2000. This OGCP document was revised in accord with requirements of the CPP, and now forms part of the conditions of approval for individual stainless steel materials and products under these Regulations.

This document provides a Code of Practice that identifies all the key requirements with regard to the use of stainless steel materials and products and provides the framework for contract document specifications. The Operational Guidelines section of the OGCP describes stainless steel materials and products in more detail and provides information on essential application, quality assurance and remedial action issues. The document is the result of a number of years of development work and experience by the material and product manufacturers, specifiers, suppliers and water industry engineers. The document may also be regarded as a summary of general “Manufacturers’ Instructions for Use” (IFU) as indicated in 1.7.8 of DWI Application Form reference 56.4.77.

Stainless steels have excellent corrosion resistance to the majority of the conditions met in water handling and treatment, providing the correct grade is selected and simple design and fabrication rules are followed. They also have excellent mechanical properties offering a good combination of strength, ductility, ease of fabrication and toughness. These attributes result in the following advantages:

X There is no dependence upon applied coatings (organic, polymeric, cementitious or metallic) for corrosion protection. Hence, no allowances for corrosion loss are required at the design stage, no constituents of the coatings are lost into the water and there is no coating maintenance.

X Their high strength and ductility mean that the weight of a component can be reduced in many cases, and resistance to impact damage during operations is enhanced.

The purpose of this OGCP is to enable plant designers, installers and operators to identify the key requirements in selecting the appropriate grade of stainless steel for equipment used for drinking water treatment and supply and also in their design, fabrication and installation.

The OGCP also provides additional information that will allow water industry engineers to specify, install and operate stainless steel materials and products. In addition it provides defined methodologies and sets out the standards to ensure that the material is applied in accordance with the conditions of approval specified for each product by the Secretary of State. The method of working specified in this document will minimise any risk of contamination of the water supply by the application and return to service of products using stainless steel materials.

The scope of this document is limited to the following topics:

1 Material Selection and Approval

Information is provided on the selection of suitable stainless steel materials and products in contact with water (which is to be supplied for drinking, washing, cooking or food production purposes – hereafter referred to as "drinking water") in the public water supply from the abstraction point to the customer supply point (stopcock), and all approval requirements.

2 Design

A detailed description is given of design for durability and of structural design procedures.

3 Construction, commissioning and operation

The fabrication, installation, maintenance and inspection of stainless steel products are highlighted and discussed.

STAINLESS STEEL PRODUCTS IN DRINKING WATER SUPPLY

CODE OF PRACTICE

PART 1 CODE OF PRACTICE (CP)

STAINLESS STEEL PRODUCTS IN DRINKING WATER SUPPLY

CP Section 1 - General

CP 1.1 Scope

This Code of Practice covers the selection of suitable stainless steel products and grades in contact with drinking water in the public water supply from the abstraction point to the customer supply point (stopcock), and all approval requirements, design for durability and structural design procedures, fabrication, installation, maintenance and inspection of such stainless steel products.

The contents of this Code of Practice have legal status (i.e. under the Water Supply/Quality Regulations 25/31) for the selection and use of stainless steel materials once individual materials and products have received Regulation 25 (1)(a) approval and/or Regulation 31 approval as the clauses of this latter Regulation are implemented. The document also contains recommendations and suggestions that are not such legal requirements. Such Regulation 25/31 legal requirements are identified by the use of the imperative term ***shall*** and are intended for use in model Specifications of Contract (which are separate documents[2] distinct from, but based on, this OGCP). The term ***shall*** in this OGCP also embraces other legal and non-legal requirements, such as for compliance with Health & Safety regulations and UK and international standards. Such compliance is clear from the context of the requirement.

Recommendations and suggestions are identified by the informative terms “should”, “may” etc. The term “should” means “ought to”or “It is recommended that…”, but is not an imperative requirement.

CP 1.2 Definitions

The following definitions apply:

Utility Representative

The person appointed by the Utility as their Representative who may or may not be a direct employee of that organisation but ***shall*** not be an employee of the Supplier or Contractor or any subsidiary/parent thereof.

The Representative's duties ***shall*** be set out in the contract between the purchaser and the supplier/contractor.

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[2] A model Specification of Contract is currently (mid 2001) under development by the stainless steel industry and other relevant parties.

Supplier

A company that is employed by a Utility or Contractor to manufacture or supply original materials and original (fabricated) products in accordance with the requirements of the Operational Guidelines and Code of Practice.

The Supplier ***shall*** ensure that all aspects of the manufacturing and supply process can be monitored and inspected by the Utility Representative.

A Supplier may also be a **Contractor** as defined below, in which case the Supplier ***shall*** act as the Contractor in approving designs or receiving materials and products from subsidiary Suppliers.

Contractor

The company that is employed by a Utility to design, fabricate, install, maintain and inspect approved materials and products in accordance with the requirements of the Operational Guidelines and Code of Practice.

The Contractor ***shall*** ensure that all aspects of the design, fabrication, installation, maintenance and inspection process can be monitored and inspected by the Utility Representative.

A Contractor may also be a **Supplier** as defined above.

The Authorities

The `Authorities' are the Secretary of State for Environment, Food and Rural Affairs (in respect of water undertakers whose areas are wholly or mainly in England) and The National Assembly for Wales (in respect of water undertakers whose areas are wholly or mainly in Wales).

CP 1.3 Reference documents

The following documents and any later revisions or editions thereof referred to in this Code of Practice ***shall*** form an integral part of the Code of Practice.

API - API Standard 650 Welded steel tanks for oil storage.
ANSI/API, 9th Ed, 1993[i].

ASME- Boiler and Pressure Vessel Code, Section VIII Pressure vessels.
ASME, 1995[ii].

AWS - D1.6: 1999 Structural Welding Code – Stainless Steel.
AWI, 1999[iii].

BSI - BS 1564:1975/1983 Specification for pressed steel sectional rectangular tanks.
BSI, 1975/1983[iv].

BSI - BS 2654 Specification for manufacture of vertical steel welded non-refrigerated storage tanks with butt-welded shells for the petroleum industry.
BSI, 1989[v].

BSI - BS EN ISO 3506:1998 – Mechanical properties of corrosion-resistant stainless steel fasteners.
BSI 1998[vi].

BSI - BS 8010 Code of practice for pipelines.
Part 2, Section 2.8 Steel for oil and gas.
BSI, 1992[vii].

BSI - BS EN 287-1:1992: Approval testing of welders for fusion welding. Steels.
BSI, 1992[viii].

BSI - BS EN 288-1 to 3 and 5 to 9:1992 to 1999: Specification and approval of welding procedures for metallic materials.
BSI, 1992 - 1999[ix].

BSI - BS EN 970:1997 Non-destructive examination of fusion welds. Visual examination.
BSI, 1997[x].

BSI - BS EN 1011-3:2000 Welding. Recommendations for welding of metallic materials. Arc welding of stainless steels.
BSI, 2000[xi].

BSI - BS EN 10088 Stainless steels. List of stainless steels.
BSI, 1995[xii].

BSI - BS EN 25817 Arc welded joints in steel - guidance on quality levels for imperfections.
BSI, 1992[xiii].

BSI - BS PD 5500 Specification for unfired fusion welded pressure vessels.
BSI, 2000[xiv.]

BSI - CP 2010 Code of practice for pipelines. Part 2 Design and construction of steel pipelines in land.
BSI, 1970[xv].

BSI - DD ENV 1090-6 Execution of steel structures; Supplementary rules for stainless steels.
BSI, 2001[xvi].

BSI - ENV 1993-1-4 Eurocode 3: Design of steel structures.

Part 1 - 4: 1996 General rules - Supplementary rules for stainless steels
BSI, 1996[xvii].

SCI - Concise guide to the structural design of stainless steel. The Steel Construction Institute, SCI-P-123, Second Edition, 1993.
SCI 1993[xviii].

SCI - Applications for stainless steel in the water industry. The Steel Construction Institute, Water Industry Guidance Note IGN 4-25-02, 1999.
SCI, 1999[xix].

CP 1.4 Inspection

All materials and products supplied and work undertaken may be subject to inspection for conformity with this OGCP, by the Utility and the Drinking Water Inspectorate (DWI) or their authorised representatives. The Supplier and/or Contractor ***shall***, when requested, provide reasonable assistance for the inspection of materials, workmanship and quality. The Utility Representative ***shall***, at all times, have access to all parts of the contract site during the entire course of the contract.

CP 1.5 Materials, products and workmanship

All materials and products supplied and work undertaken ***shall*** be approved by the Authorities to Regulation 25 (1)(a) and/or Regulation 31. Where stainless steel is physically joined to other materials that are in contact with water, then those materials ***shall*** also be currently approved by the Authorities to those Regulations, subject to the provisos and exemptions for small surface area contact.

Stainless steel materials ***shall*** be as defined in (preferably) BS EN 10088[xii] (see CP 1.3), or a current equivalent national or international specification (*e.g.* – ASTM/ISO/SS).

CP Section 2 – Design

CP 2.1 Durability

The process specification and plant component design ***shall*** be examined by the Contractor to assess potential corrosion hazards.

CP 2.2 Choice of stainless steel grade

The Contractor ***shall*** be responsible for grade selection, with particular consideration of chloride levels and material carbon content or stabilisation in relation to welding. Free-cutting high sulphur or selenium bearing grades ***shall*** not be permitted.

CP 2.3 Structural design

Structural design ***shall*** be agreed between the Contractor and the product/material Supplier(s) and may make reference to the *Concise guide to the structural design of stainless steel*[xviii] (and/or other published design tables), the European PreStandard, Eurocode 3: Part 1 - 4[xvii], covering the structural design of stainless steel members, and/or design guidance on stainless steel fixings and ancillary components[xx, xxi, xxii].

CP 2.4 Tanks and vessels

Tanks

Design of welded and bolted tanks ***shall*** be agreed between the Contractor and the Supplier. Reference may be made to American Petroleum Institute Standard API 650[i], the British Standard BS1564[iv] or BS 2654[v].

Welded pressure vessels

Welded pressure vessels in stainless steels ***shall*** be designed to the requirements of the appropriate design codes, e.g. PD 5500: 2000[xiv], the ASME Code[ii] (see CP 1.3), which also refer to the appropriate material properties for the stainless steels to be used.

CP 2.5 Pipework systems

Pipework systems, as with pressure vessels, ***shall*** be designed to contract requirements in accordance with appropriate industry, national or international design standards. Selection of piping systems is dictated by operating conditions.

The design ***shall*** utilise safety factors appropriate to the service conditions and the required levels of inspection and quality, in order to produce a safe design that satisfies both the Utility and the insurance authorities or certifying bodies.

CP 2.6 Fabrication design

The Contractor ***shall*** communicate clearly, to all parties involved in the fabrication process, the requirements for production routines, welding and fabrication, NDE and quality assurance, at the design phase.

CP Section 3 - Fabrication

CP 3.1 Materials handling and storage

1 As cleanliness is the most important aspect of operations with stainless steel, care ***shall*** be taken to keep the steel clean and free from contamination during storage, handling and fabrication. Further recommendations and advice are contained in EN 1011-3, Section 5[xi] (see CP 1.3).

2 In order to minimise potential corrosion damage or unsightly surface marking, measures ***shall*** be taken to prevent contamination by iron, aluminium, copper, chlorides, sulphides (or other

contaminants) from lifting equipment, marker pens, airborne contamination from adjacent fabrication areas and tooling. Any resultant incidental contamination ***shall*** be removed at the earliest opportunity.

3 Plate and pipe lifting and storage methods ***shall*** minimise damage or contamination of the steel. Iron particles embedded in stainless steel surfaces during fabrication are a cause of 'surface rusting'. For example, stainless steel slippers or wooden packers should be used on forklift trucks to prevent contamination. Any resultant incidental contamination ***shall*** be removed at the earliest opportunity.

4 Stainless steel materials and products ***shall*** be stored separately from carbon steels and non-ferrous materials. Materials should be stored under conditions that minimise the accumulation of dust and deposits, particularly in industrial or marine locations. Any resultant incidental contamination ***shall*** be removed at the earliest opportunity.

CP 3.2 Welding

Stainless steels are readily weldable by manual or automated techniques. All the standard arc welding processes can be used.

1 The specification for the fusion welding of stainless steels ***shall*** be in accord with BS EN1011-3[xi] (see CP 1.3).

2 Welding ***shall*** be undertaken in accordance with a written welding procedure, with both welder and procedure qualified to the welding standard being followed (BS EN 287[viii] and 288[ix]) respectively.

3 Filler materials ***shall*** be selected having regard for the parent materials and the particular application and ***shall*** comply with relevant standards.

4 Risk of contamination of the weld region from any copper strips (e.g. welding fixtures, earth clamps or manipulators) ***shall*** be minimised.

Cleanliness and gas shielding

The importance of cleanliness has been addressed in the context of materials handling; it is even more important during welding. Further recommendations and advice are contained in EN 1011-3[xi] (CP 1.3).

5 Prior to welding, the weld zone ***shall*** be free from oil, grease, other surface contamination and excessive oxidation, as far as is practicable.

6 Contamination of the weld zone, particularly by iron, copper, zinc, lead, ***shall*** be minimised. Tooling should be chosen and used accordingly (*e.g.* iron-free slitting wheels and grinding discs should be used), and standard welding wire and flux storage and handling requirements should be followed to ensure cleanliness and dryness of the materials.

7 An inert backing gas or mixture ***shall*** be used to protect the penetration bead of single-sided, full-penetration welds from oxidation, including tack welds. Shielding gas or mixture ***shall*** be maintained for a sufficient duration to ensure that the finished weld surface oxidation is contractually acceptable, in accordance with EN 1011, Section 7.3 VIII[xi] (CP 1.3). These requirements are essential for optimum corrosion performance where there will be no access for subsequent cleaning of the weld surface, as in single-sided full-penetration butt welds for tube joints. Where the use of an inert backing gas or mixture is impractical, as in some site closure welds or where internal access is poor, then a shielding paste or tape may be used as an alternative, after submitting a suitable qualified procedure and gaining Contractor approval. The paste or tape/adhesive ***shall*** be completely removed after welding. Where access does not permit full removal, then mechanical joints should be used.

CP 3.3 Post-weld cleaning

1 In order to achieve the optimum corrosion performance of stainless steel welded joints, crevice features, contamination and at least all weld heat tints deeper in colour than a pale yellow ***shall*** be removed by mechanical dressing followed by acid pickling of the joint. This requirement may be relaxed, however, where acid pickling cannot be carried out (such as for environmental reasons), when mechanical dressing, blasting – and in particular - grinding – may be used, by agreement with the Contractor, as an alternative to acid pickling. Electro-cleaning may also be used as an alternative to acid pickling.

2 For mechanical cleaning, all abrasive media ***shall*** be iron-free and wire brushes ***shall*** be made of a suitable grade of stainless steel wire, be stored in clean conditions and not be used for any other purpose, to avoid contamination.

CP 3.4 Weld inspection and acceptance

1 Examination procedures on weld acceptance ***shall*** be as BS EN 25817[xiii] (CP 1.3). The Contractor ***shall*** define the requirements, within the purchase specification, for the following, specifically:

- The type of test/examination method that ***shall*** be used and the relevant standards.
- The weld acceptance criteria that ***shall*** be applied.
- The proportion of the welding that ***shall*** be inspected.

2 Visual inspection of all welds ***shall*** be a minimum requirement in all cases. Guidance on the visual examination of welded joints is given in BS EN 970[x] (see CP 1.3). 100% of the weld cap ***shall*** be examined and as much of the root side as is accessible.

3 The fabricator (Contractor) ***shall*** be satisfied that the welder is competent to complete the first stage inspection indicated in CP 3.4 2 above.

4 Weld quality ***shall*** comply with the requirements of the standard quoted in the specification.

CP Section 4 - Installation, Maintenance and Inspection

CP 4.1 General design/fabrication/operational principles

1 DD ENV 1090-6[xvi] (See CP 1.3) ***shall*** be implemented.

2 Fabrication ***shall*** be designed, and operational action ***shall*** be taken, to prevent hydrotest water (or water used for other commissioning, settling and run in procedures) from remaining stagnant within the pipework for more than 5 days after testing. The cleanest, low chloride water available should be used for the testing (*i.e.* demineralised, steam condensate, potable etc.).

3 After hydrostatic pressure testing or other procedures, and regardless of water quality, water ***shall*** be drained completely or circulated for one hour every two days. After draining, the pipework ***shall*** be inspected to ensure dryness.

CP 4.2 Site fabrication and installation

1 During fabrication, welding operations carried out under workshop conditions ***shall*** be preferred to welding on-site.

2 Tie-in welding may be necessary at some locations. Pipe ends should be cold cut to length and then prepared. Pipe ends ***shall*** be prepared for welding with the same care and attention as joints prepared for fabrication under workshop conditions. Where slitting wheels and grinding discs are used, heat tints ***shall*** be removed (see also CP 3.3).

3 The pipe end ***shall*** be prepared for welding with the same care and attention as for a shop fabrication joint. Pipe end preparing machines are preferred in order to produce a reliable joint bevel (if required) and joint fit up.

4 The gas backing requirements specified in CP 3.2 Welding above ***shall*** be applied. Bladders or dissolvable gas dams can be used to reduce the purged volume.

5 Suppliers ***shall*** advise if stainless steel pipework systems, packaged units, plant and other equipment involving stainless steel require further treatment after installation.

6 All reasonable care ***shall*** be taken to avoid damage and contamination on site. Contamination ***shall*** be removed by suitable means. Under no circumstances ***shall*** mortar cleaners based on hydrochloric acid be used on stainless steels.

CP 4.3 Pipe burial

The same general principles for the handling and burial of carbon steel pipe ***shall*** apply to stainless steels - see for example BS 8010: Part 2.8[vii] and CP 2010: Part 2[xv] (CP 1.3). See also CP 3.1 above.

1 In assessing corrosion risks, the preliminary site survey ***shall*** take account of soil chemistry, structure and drainage as well as the possible presence of stray electrical fields.

2 The risks of post-installation contamination, from de-icing salts and other sources, for pipes laid under roads, ***shall*** be assessed.

3 Precautions ***shall*** be taken to prevent damage on lifting and laying, dirt, contamination and small animals entering partly completed lines, and inadequate drainage.

4 It should be remembered that stainless steel pipes, although very ductile, are likely to be of thinner wall section than ductile iron or some carbon steel equivalents. Accordingly, an inert, smooth, fine bedding and back-fill material ***shall*** be selected to avoid the risk of rocks or irregular stones denting the pipe wall during laying and covering operations. Suitable load-bearing performance for the restored surface ***shall*** be established.

CP 4.4 Specialised protection, painting, minor fitments and insulation

The use of external paint coatings on stainless steel equipment tends to be reserved for special circumstances – *e.g.* - in applications where protection is required against local concentration of chloride or aggressive solutions but where the associated risk does not justify a material upgrade, or for identification/aesthetic reasons. See SSAS Information Sheet SSAS5.80 *Paint Coating of Stainless Steel* [xxiii], which contains reference to BS and ISO standards.

Paint coatings are sometimes used on the external surfaces of pipes in conjunction with thermal insulation. See SSAS Information Sheet SSAS5.81 *Corrosion Barriers for Thermally Insulated Stainless Steel* [xxiv].

1 The Contractor ***shall*** seek advice from the Paint manufacturers on the combination of surface treatment, primer and finishing coat combinations suited to a given environment, to minimise crevices and galvanic couples.

2 Any coating systems in contact with drinking water ***shall*** take into account the water contact requirements set out in relevant Authorities approval for such materials.

3 The use of zinc-rich paints on stainless steels ***shall*** be avoided.

4 The attachment of features such as identity tags or earth continuity leads to stainless steel components ***shall*** be agreed with the Contractor, especially if made post-installation.

5 The components in direct contact with the stainless steel ***shall*** be made of a grade of stainless steel (or other material) matching (or not compromising) the corrosion performance of the parent material and fitted in such a way as to minimise crevices. If stud or tack welding is used, a clean finish is essential and the heat input ***shall*** be adjusted to minimise heat tinting on the inaccessible inner side of the component.

CP 4.5 Inspection

Inspection levels for components and welded joints, together with the weld acceptance criteria, ***shall*** be as given in the relevant design standard or as otherwise agreed in the contract.

CP 4.6 Cleaning

Surfaces in contact with treated water must be cleaned, disinfected and flushed in accordance with the requirements of the water supplier before being brought into service. The cleaning agents and disinfectants ***shall*** be suitable for use with stainless steel.

STAINLESS STEEL PRODUCTS IN DRINKING WATER SUPPLY

OPERATIONAL GUIDELINES

PART 2 OPERATIONAL GUIDELINES (OG)

OG Section 1 - Purpose

Reference is made in the following operational guidelines to the preceding CP sections, and further recommendations, information and advice are offered. Further guidance will be found in *Applications for stainless steel in the water industry*[xix] and *Stainless steel for potable water treatment plants*[xxv]. The main text of this OG refers to BS EN 10088 designations for stainless steels. The popular names of the nearest equivalent stainless steels (*e.g*. '304' and '316') types can be found in the Appendix Table.

OG Section 2 - Design

OG 2.1 Durability

See CP 2.1. The majority of corrosion problems should be anticipated and are avoidable. Good design, appropriate steel grade selection, good specification and control over fabrication methods, correct commissioning and operating practices all combine to give long plant life.

OG 2.2 Choice of stainless steel grade

See CP 2.2.

1 The Appendix Table provides examples from within the major families of stainless steels, their compositions and attributes. The EN designations are also given together with their popular names. The popular names largely originate from the now superseded British Standards and AISI system.

2 Type 1.4301 (304) and 1.4401/4436 (316) austenitic grades of stainless steel can be used for the majority of applications in drinking water treatment and supply. Selection depends primarily on whether it is to be welded, the chloride or chlorination levels of the water and also on the severity of the crevices the alloys are exposed to.

3 The molybdenum-containing type 1.4401/4436 (316) grades have a higher corrosion resistance than the type 1.4301 (304) grades and are more suitable for higher levels of chloride. They are also preferred when more severe crevice conditions are anticipated or when a greater level of conservatism is required.

4 For resistance to atmospheric environments, type 1.4301 (304) grades will normally provide adequate service. However, in coastal regions where the atmosphere is salt laden or in industrially polluted regions, the type 1.4401/4436 (316) grades of stainless steel will have better corrosion resistance and retain their surface lustre longer. Regular washing of these structures will also assist in service performance.

5 Subject to the requirements for good design and standards of workmanship, type 1.4301 (304) grades may be used in most flowing water systems where chloride levels are less than 200 ppm (at temperatures normally encountered in drinking water supply and treatment). They are well suited to applications where abrasion and erosion resistance are required, as in screens and grids.

6 The molybdenum-containing type 1.4401/4436 (316) grades, with their higher resistance to pitting and crevice corrosion, may be used for waters with chloride levels of up to 1000 ppm under the same conditions (at temperatures normally encountered in drinking water supply and treatment).

7 Where the alloys are to be used in higher chloride levels than given in this OGCP document, the supplier should be required to demonstrate fitness for purpose by existing experience in equivalent environments and sound engineering/corrosion science.

8 It is important to note that crevice corrosion can occur on rare occasions at chloride conditions below those mentioned. This may be due to local environments where chlorides can concentrate or where the protective surface oxide film is weakened. A more conservative approach in such situations would be to use type 1.4301 (304) up to 50 ppm and type 1.4401/4436 (316) up to 250 ppm chlorides (at temperatures normally encountered in drinking water supply and treatment). There have been instances of good performance at chloride levels above 200ppm with 304 and 1000ppm with 316, where good flow is maintained, the metal surface is kept clean and surface deposits and crevices are avoided. Higher chloride levels can also be tolerated if the stainless steel is galvanically protected.

For chloride levels up to 3,600ppm, alloy 1.4462 (2205), super austenitic and super duplex grades can be used. For 3,600-26,000ppm (sea water) then super duplex and super austenitic grades are more appropriate.

The following table is a summary of the suitability of stainless steels in various waters at temperatures normally encountered in drinking water supply and treatment (adapted from SSAS Information Sheet 4.92[xxvi]). For higher temperatures or pH levels below 6, specialist advice should be sought.

Water Type	Chloride level ppm	Comment	Stainless Steel grades Popular name
Pure water			304
Supply water	<350	1.4301 (304) suitable up to 200ppm	304,316
Fresh water or ground water	<1000	1.4301 (304) suitable up to 200ppm only	304, 316 2205, Super austenitic, Super duplex
Brackish water	10,000-15,000	Estuary or tidal waters 2205 suitable up to 3,600ppm only	2205, Super austenitic Super duplex
Sea water	15,000-26,000 (2.5-4% NaCl)		Super duplex Super austenitic

Stainless steels are usually resistant to most chemicals used in drinking water treatment, but some chemicals such as high levels of chlorine and ferric chloride can be very aggressive. The presence of the oxidising agent chlorine increases the possibility of crevice corrosion for a given level of chloride in waters. In flowing raw waters, then the type 1.4301 (304) grades may be used for chlorine levels up to 2 ppm. The type 1.4401/4436 (316) grades offer a greater margin of corrosion performance. High levels of chlorine for short periods of time for disinfection purposes (e.g. 25ppm for 24 hours) can be tolerated but it is essential to flush this away directly afterwards.

In areas of plant where moist chlorine vapours collect and concentrate, staining and localised pitting may occur. In such conditions, good ventilation, occasional wash downs to remove chemical build up or, if not possible, a more corrosion resistant grade of stainless steel is advisable.

Good system design, good fabrication practices and operational maintenance are necessary to obtain the optimum performance from stainless steels, whatever the grade selected.

Special grades are available for unusual environments and applications requiring high strength (see Appendix Table). For temperatures above 50^{o} C, where chloride stress corrosion cracking can be a risk, Types 1.4301 (304) /1.4401/4436 (316) are usually inadequate. Duplex, super austenitic and ferritic stainless steels should be considered.

OG 2.3 Structural design

See CP 2.3. The design of any items of process plant, irrespective of the type of material, involves two distinct and equally important phases:

- Structural design to withstand the service conditions (*i.e.* to ensure adequate strength, stability, stiffness, durability *etc*.)

- Design for fabrication, relating contract specification, structural design and fabrication with commissioning and handover.

Where possible, the plant should be designed to:

1 Have free liquid flow, avoiding regions of stagnation and dead legs, low flow and deposit build-up.

2 Have, where flow is intermittent, any horizontal pipe runs and tank bottoms sloped to allow complete draining.

3 Where light gauge stainless steel pipework is used, have the mounting methods take account of any acoustic damping required as a result of pressure pulsing. Acoustic damping may benefit from the use of double swept tees to avoid sharp internal edges in the pipework and subsequent eddy formation.

4 Ensure deposit traps and crevices are eliminated as far as possible (*e.g.* if plates are lapped, all lapping edges to be sealed).

5 Provide weld procedures appropriate to the design and grade of steel being used.

6 Ensure that the fabrication route allows easy access for welding, to achieve the optimum geometry of weld and ease of final finishing or the avoidance of heat tint formation.

7 Give conditions allowing full-penetration welded joints with smooth contours and weld bead profiles.

8 Avoid creating galvanic couples and identify precautions when such couples cannot be avoided.

Where deposits are unavoidable, dismantling may be undertaken, or ports should be provided to allow access for cleaning (schedules should be specified for flushing out). For example, raw water lines, where manganese and iron-bearing deposits may form ahead of sand filters, provision for periodic flushing and hydroblast cleaning should be made.

Schedules should be specified for prolonged plant shutdowns. For example, to prevent corrosive deposit formation due to drying out, specify either that pipework should be kept wet by circulating water for a minimum of one hour every two days, or that pipework should be flushed with clean water, drained completely and blown down to dry out.

OG 2.4 Tanks and vessels

See CP 2.4. Stainless steel tanks may be assembled by using bolted connections with mastic joints. However, welded assemblies are preferred; especially, when used in conjunction with good fabrication practices, there is a reduced potential to form crevices.

Although stainless steel may be welded on site, it is generally recommended that tanks should be fabricated under workshop conditions wherever transportation of the finished product is practicable. Manufacture of the tank in a workshop off-site (while site preparation works are being undertaken) provides a cleaner and more controlled working environment (and maximises the speed and efficiency of the construction process).

Rectangular tanks may be formed from profiled panels or stiffened plate. For stiffened plate construction, the plate forming the shell acts like a wide beam between support lines that are either stiffeners or the other walls of the tank. The plate should be designed according to the recommendations in the SCI *Concise guide to the structural design of stainless steel* [xviii] for members in bending. Vertical stiffeners may be supported by ring frames or ties at the top and bottom of the tank and welded to the shell plate. They may be designed as simply supported beams.

To counter specific corrosion conditions, stainless steel sheeting may be used to line either existing or new concrete vessels, or for groundwater separation membranes. Both circular and rectangular vessels may be lined (‘wall-papered’) using methods generally accepted within the pulp and paper industry. The lining forms a clean and hygienic surface. Typical thickness varies from 2 - 3 mm. Adherence to established techniques for the application of linings based on welding sheets onto pre-fixed stainless steel backing strips is recommended.

OG 2.5 Pipework systems

See CP 2.5. A variety of stainless steel process piping systems may be used, all using principal steel grades equivalent to the 1.4301 (304) and 1.4436 (316) austenitic steels and each having its own attributes and benefits. There are also other standards used in the chemical, food/dairy and plumbing industries.

ANSI - Traditionally used worldwide as the standard for process piping systems. It was developed from American carbon steel specifications for high pressure and temperature requirements.

ISO - The international standard for process piping utilising ANSI outside diameter sizes but with more appropriate wall thickness reflecting the strength and corrosion resistance of stainless steel.

Both the ANSI and the ISO systems are restricted to the use of welding or threaded joining systems.

Swedish - The Swedish metric system is characterised by having a uniform bore diameter through tube and fittings for any one specified pipe size from 4mm to 1200 mm internal diameter, with wall thickness of 1, 2 or 3 mm. It offers a lightweight design solution where free flow of liquids and semi-solids is required at up to 16-bar pressure. Joining is generally by butt-welding. This pipework system is manufactured to Swedish materials, design, dimensions and testing standards. The principal steel grades used are equivalent to the 1.4301 (304/SS2333) and 1.4436 (316 high molybdenum/SS2343) austenitic steels.

BS 4127 - The BS 4127 system offers the widest range of joining techniques. It specifies requirements for light gauge stainless steel tubes, primarily for water applications, suitable for connection by capillary fittings (for adhesive bonding or silver brazing), compression fittings, or by inert gas welding. The size range is from 6mm to 159mm outside diameter, with wall thicknesses from 0.6mm to 2mm. This system is being extended as a European Standard (BS EN 10312), which will incorporate an extended combination of outside diameters and wall thicknesses, and press fittings. Grades 1.430l and 1.4436 (304 and 316) are standard, but it is specified that other grades can be used.

The table below gives typical national/international standards for design, dimensions and testing. See SCI IGN 4-25-02 *Applications for stainless steel in the water industry* Appendix B[xix] for further details of these standards.

Other appropriate pipework/tube standards include those for (usually smaller) diameters used in the chemical, food/dairy and plumbing industries[xxvii, xxviii, xxix, xxx, xxxi, xxxii].

System	**Design standard**	**Dimension**	**Testing**
ANSI	ASME B31.3	ASME B36.10 ASME B16.9 (fittings) ASTM A774 (fittings)	ASTM A312 (pipe) ASTM A403 (fittings) ASTM A774 (fittings) ASTM A530 (pipe)
ISO	DIN 2413	ISO 1127 (pipe) ISO 5251 (fittings) ISO 5252 (tolerances) PrEN 10253-2 (fittings)	DIN 17457 DIN 17455 PrEN 10217-7 (tube)
Swedish	RN 1978/37	SSG 1361	SS 219711 SS 219716
BS4127(BS EN 10312)	ASME B31.3	BS 4127 (BS EN 10312)	BS 4127 (BS EN 10312)

There may be some difficulty in applying the welding inspection criteria to thin wall tubing - especially with respect to misalignment (*e.g.* BS 5289 gives a wider acceptable tolerance than the pipe wall thickness).

Water industry standards adopt the same principles as national or international standards but are generally less onerous because the service conditions are less severe than those anticipated by many national or international standards. For example, the use of the actual material strength (at temperature) rather than the minimum specified values may be adopted. Such differences may well have limited significance at low pressures as fabrication and installation aspects rather than service and pressure requirements generally determine the pipe wall thickness.

Duplex and higher alloy austenitic stainless steels may be appropriate for pipework in areas where enhanced corrosion resistance is required or where it is appropriate to utilise the higher strength of these alloys.

When backing rings and loose flanges are used, and the external atmosphere is not aggressive, it may be a more economic choice to use non-stainless loose flanges (*e.g.* made from coated mild steel or aluminium), if galvanic corrosion can be avoided.

OG 2.6 Fabrication Design

See CP 2.6. The principle of design for fabrication is that the contract specification is converted into a design, which can be built efficiently. This affects all aspects of fabrication, including documentation, and involves ensuring that the work in progress is maintained at an efficient and steady level.

As thin-skinned structures (especially flat plate for tankage or architectural applications) can experience unacceptable fabrication-induced buckling distortion, structural design should take into account fabrication stresses as well as plate thickness and material physical properties if flat, plane surfaces are to be produced. Heat line straightening techniques that may be appropriate for carbon steels should not be used to correct distortion in stainless steel. Correct fabrication first time is crucial.

OG Section 3 - Fabrication

In general, care should be taken not to walk on structural components and pipework systems, nor to subject them to any other undue stresses. Pipe ends should be capped and other components protected as far as possible during fabrication.

The thickness of most stainless steel structural components and pipework systems used will be governed by fabrication and installation considerations. Because of the absence of corrosion allowances, minimum thickness is often determined by the need to resist distortion and impact damage, rather than service or pressure loadings. Appropriate quality assurance and control routines should be used for all aspects of fabrication.

The requirements for duplex and more highly alloyed austenitic stainless steels are very similar to those of the standard austenitic steels, but require slightly more attention to detail. Specialist advice, however, should be taken in order to optimise fabrication and production routines to achieve the full corrosion and strength characteristics of these steels.

OG 3.1 Materials handling and storage - Cutting, forming and machining

See CP 3.1.

Thermal (except oxy-acetylene) and cold cutting techniques may be used on stainless steels. The steel can be guillotined, sheared and sawn on standard machine tools. Cold forming with standard equipment is generally appropriate for thicknesses up to about 8 mm. When bending, shearing and guillotining, the capacity of the equipment should be downrated to about 50-60% relative to carbon steels, because of the work hardening characteristics of the austenitic grades.

1 Clearance between the blades should be maintained at 3-5% of the plate thickness using true, sharp blades. The cut edges should be examined for contamination and, particularly if there will be subsequent cold work, should be dressed smooth.

2 When sawing stainless steel, sharp, high-speed steel (or carbide/PCD-tipped, or other appropriate blades) should be used, with cutting fluids. For thickness of 3-6 mm, blades with approximately 10 teeth per inch (or more) are appropriate. The sawing efficiency will be considerably improved by ensuring that, on the return stroke, the blade does not drag in the groove. It should lift clear of the cutting face to minimise work hardening effects.

3 Thermal cutting can be successfully completed with plasma and laser cutting. The cutting kerfs and heat-affected zone should be removed before further processing is undertaken.

Although the austenitic stainless steels retain their ductility after forming to a greater extent than carbon steels, it must be remembered that the duplex steels have higher yield strengths and are less suited to extensive cold working.

1 Contamination from iron particles by pressure contact with rollers or tooling should be avoided. Local application of adhesive plastic films or tape can be used to prevent direct contact and should be removed after fabrication is completed.

2 Cold forming equipment for stainless steels should be of adequate rigidity and power to cope with the higher work hardening rates.

3 Generally, the maximum thickness handled in standard equipment should be downrated by about 50% compared with structural carbon steels. Allowance must also be made in bending and rolling for the greater springback characteristics of stainless steels.

4 Where dished heads are pressed and spun on standard equipment, and multiple sheets simultaneously pressed, then contamination of the stainless steel by the press head should be avoided.

5 Pipe bending and other fabrication activities on site should be avoided as far as possible. Straight pipe runs may be connected with elbows and bends in the normal manner. Spooling is preferred.

OG 3.2 Welding

See CP 3.2. The combination of gas purity and purging system employed should ensure levels of root oxidation, as required by the design specification, as referred to in EN 1011, Section 7.3[xi] at the weld location (including tack welds).

The welding process should be selected to balance factors such as the grade of material and corrosion performance, thickness, skill requirements and joint completion rates. The principal welding methods are TIG (GTA), MIG (GMA) and their variants, plasma (PAW), MMA (SMA), Submerged Arc Welding (SAW) for tank fabrication and Stud Welding (SW) in lining systems. Light gauge materials, including pipework, are often welded using TIG.

The following table lists some of the factors that should be taken into account when welding stainless steels. Many of them are common to welding other steels; specific comments on certain aspects are given below. Whilst the same principles apply when welding duplex or more highly alloyed austenitic stainless steels, the attention to detail may be different and specialist advice should be taken, especially regarding design for ease of fabrication.

Weld procedure Process Consumable Bevels Fit-up Backing Welding technique (balanced passes)	**Heat input** Root pass Fill and cap passes Stop/starts Weld volume Deposition rate Welding position
Temperature Preheat Interpass Post weld heat treatment	**Cleanliness** Joint preparation (degreasing and Mechanical cleaning) Consumable Shielding gas Backing gas

Temperatures

Unlike some carbon and alloy steels, austenitic stainless steels can be welded at room temperature and hence do not normally require preheating. Low heat input is desirable for austenitic stainless steels while controlled heat conditions are required for duplex stainless steels.

Interpass temperature is the maximum temperature of the weld zone allowed immediately prior to starting any subsequent weld pass, and is normally measured with a contact pyrometer. Temperature indicating crayons should only be used with great caution as they can leave a contaminating deposit in the weld zone. A maximum interpass temperature of 150°C is appropriate for type 1.4301 (304) and 1.4401/4436 (316) grades.

Post-weld heat treatment is not normally necessary for austenitic or duplex stainless steels.

Gas-shielding

Shielding gases or mixtures used when welding stainless steels include, argon, argon-oxygen, and proprietary mixtures (of eg argon, helium, nitrogen and carbon dioxide). The latter two are preferred for the MIG process, since they improve arc stability and weld metal wetting. Argon is normally specified as a backing gas, although a 90% nitrogen - 10% hydrogen gas mixture may also be used. Where access to the underside of a weld is difficult after completion of a weld, as in closing joints, purging may still be possible e.g. by the use of water-soluble dams. In cases in which the integrity of the weld cannot be guaranteed, a bolted joint may be preferable to a welded joint.

OG 3.3 Post-weld cleaning

See CP 3.3.

1 For optimum corrosion performance both oxide films and any chromium-depleted layers beneath it should be removed from the weld area.

2 The extent to which heat tinting should be removed before the item is put into service is dictated by the type of component and its environment. Ideally, all heat tint should be removed, but, as a general rule, anything other than a pale yellow coloured oxide film should be removed. (Oxide film colours vary from pale yellow to brown to blue to black as its thickness increases.)

3 Heat tint and contamination can be removed by mechanical or chemical means.

4 Brushing with stainless steel brushes, blasting with glass beads or walnut shells, and grinding are effective to different degrees.

5 Generally, mechanically cleaned surfaces should be taken to at least a 180-grit finish.

6 Pickling would generally be used after mechanical cleaning but can be applied as an alternative to mechanical procedures. Mixtures of nitric and hydrofluoric acid are applied by immersion, by spraying, or locally in paste form. Thorough rinsing is essential and care must be taken not to over-pickle. Safe working practices must be followed. It is important that all pickling residues are removed by thorough rinsing with water. (cf. CP 3.3)

7 For certain, principally hygienic, requirements, a finer mechanical polish followed by electro-polishing is appropriate. Electrocleaning/polishing is an alternative procedure, requiring special power sources and tools.

8 Cleaning and passivation of stainless steels is covered by the specification ASTM A 380 - 99 '*Cleaning, descaling and passivation of stainless steel parts, equipment and systems*'[xxxiii].

Pickling and passivating

Definitions:

Pickling is a process that removes heat tint, embedded iron particles and other surface defects produced during fabrication. A nitric acid-hydrofluoric acid mixture removes the oxide layer and a thin layer of the substrate metal to reveal a uniformly clean surface. During and after rinsing with water, the normal protective oxide film re-forms evenly over the treated surface. Pickling may be carried out by immersion, by spraying when fabrications are too large for immersion, or by application of an acids-containing paste for local treatment of weld joints.

Passivation is the process by which a stainless steel spontaneously forms a chemically inactive surface when exposed to air. The protective nature of the surface film can be enhanced by application of nitric or mild organic acids, as a separate treatment after pickling.

OG Section 4 - Installation, Maintenance and Inspection

OG 4.1 General design/fabrication/operational principles

See CP 4.1. No further advice is presented in this OGCP document. Reference for further information should be made to *Applications for stainless steel in the water industry*[xix] and *Stainless steel for potable water treatment plants*[xxv].

OG 4.2 Site fabrication and installation

See CP 4.2.

1 Prefabricated assemblies should be protected from dust, mechanical damage and the ingress

of contamination by the use of covers and end caps prior to final assembly.

2 Temporary coverings should be used to protect assemblies from grinding, concrete and masonry dust.

3 As in the initial storage and fabrication stages, precautions should be taken to minimise contamination with iron particles, either as dust or spatter from cutting or sawing operations, or embedded by contact, for example as a result of scaffold poles being dragged over the metal.

4 Any resulting incidental iron contamination may be readily removed by applying a nitric acid based cleaning agent, where contamination is superficial, or a pickling agent, where embedded. Proprietary formulations are available.

5 If surface dust contamination is heavy, stainless steel components should be thoroughly washed down during construction. In any case, it is preferred that plant should be washed down with drinking grade water at the end of installation operations.

6 Pipework systems should be flushed through to remove any debris and, if left to stand empty prior to commissioning, washed with drinking water and dried[xxxiv].

Components should be prefabricated for mechanical fastening, taking advantage of the range of conversion couplings available, or for tie-in welding. Pipework systems should be spooled. Spool pieces and pressure vessels joined with stainless steel connections should be bolted using compatible stainless steel bolts. Reference should be made to BS EN ISO 3506:1998[vi] – Mechanical properties of corrosion-resistant stainless steel fasteners.

OG 4.3 Pipe burial

See CP 4.3. If a risk assessment indicates that de-icing salt or other contamination may occasionally attack part of a buried pipe, then local protection of the pipe using suitable wrapping material should be considered by the Contractor.

OG 4.4 Specialised protection, painting, minor fitments and insulation

See CP 4.4. The risk of chloride-induced stress corrosion cracking (SCC) is addressed in Reference XXI[xix], which outlines the selection of insulation and protection of pipework and tank systems that may operate at temperatures above about 50°C. Guidance on galvanic behaviour is also given in this reference.

Initial surface preparation should observe the requirement to avoid contamination by iron. Thin gauge stainless steel surfaces may be distorted or damaged by conventional abrasive blasting operations that are normally used to provide a keying surface.

OG 4.5 Inspection

See CP 4.5. It is very unlikely that a problem of uniform corrosion (extensive and nearly uniform loss of section) will be encountered with stainless steels in water industry plant. Accordingly, conventional wall thickness checks using appropriate ultrasonic equipment are normally only needed in regions that are subject to abrasive wear.

The main objective of inspection should be to check for any localised corrosion at critical locations. These should include, on external structures:

1 Where there are dirt and deposit traps sheltered from rainwater washing, and regions exposed to evaporating liquids from leaks and dribbles.

2 Any sites of brown staining. On newly commissioned plant this is often a result of undetected iron contamination that only becomes apparent early in the life of the plant. Once the iron contamination is detected and removed, this staining does not recur. Recurrent brown staining is an indication of the presence of a corrosive agent, such as a combination of chlorine gas and moisture.

3 Once the staining has been removed, a check can be made for the presence of localised pitting. This can be done with a ×10 or ×20 hand lens. A portable microscope with a suitable focussing mechanism capable of displacements in steps of the order of 0.002 mm can be used if it is necessary to measure micropit depths.

4 The same general principles apply to internal surfaces. The following should be checked:

- Areas under deposits in 'dead' areas and any 'waterline' markings in vapour spaces after the removal of the deposits.

- It is preferred that flange-gasket surfaces in systems carrying corrosive media be checked periodically for crevice corrosion. Similarly, rubbing surfaces such as valve spindles and balls, or pump components, should be checked at a frequency advised by the manufacturer (Supplier).

OG 4.6 Maintenance

Stainless steels require little maintenance, however attention is drawn to the following points about avoiding build-up of dirt deposits and crevice conditions on both the inside and outside of components.

1 In marine, salt-spray environments, and in enclosed chambers where there is chlorine present in the atmosphere, regular wash-down procedures are preferred (with clean, low chloride

water e.g. potable water) to maintain a good surface condition.

2 At non-coastal sites, free exposure to rainwater is often enough to keep most stainless steel components clean, with periodic washing down (with clean, low chloride water e.g. potable water) of shadowed or dribble regions as necessary.

Repairs and modifications should be designed, specified and executed to the same standards as for the original equipment.

APPENDIX

Stainless Steels Table and Information

Table – Contents of main alloying elements in selected grades of stainless steels

Family	BS EN 10088 designation	Popular name(1)	Content of alloying element (maximum or range permitted) weight %							Attributes/Comments
			C	Cr	Ni	Mo	Cu	N	Others	
Ferritic	1.4512	409	0.03	10.5-12.5	-	-	-	-	Ti(2)	Lower corrosion resistance than 1.4301 (304) and with more restricted fabrication properties. Grades 1.4512 (409) and 1.4016 (430) are welded only in sections thinner than 3 mm. Grade 1.4003 has better weldability and is suited to applications involving abrasion and wear. Ferritic grades 1.4510 and 1.4511 (X3CrTi17 and X3CrNb17) are used in water supply in Europe. For 17% Cr steels, a low carbon (<0.03%) and stabilised grade must be used (e.g. 1.4510,1.4511 and 1.4521).
	1.4003		0.03	10.5-12.5	0.3-1.0	-	-	-	-	
	1.4016	430	0.08	16.0-18.0	-	-	-	-	-	
	1.4521		0.025	17.0-20.0		1.8-2.5		0.03	Ti(2	Ti content minimum = 0.15 + 4(C+N), typically 0.8%.
Austenitic	1.4307	304L	0.03	17.5-19.5	8.0-10.0	-	-	-	-	This family of stainless steels meet most of the requirements in the water industries. Good combination of corrosion resistance, forming and fabrication properties; readily available. The principal difference between the standard and lower carbon 'L' grades is that the latter have greater resistance to sensitisation (reduction in corrosion resistance) in weld heat affected zones. The pitting and crevice corrosion resistance increases as the molybdenum content is raised from 1.4301, through 1.4401 to 1.4436 (304, through 316 to 316 high Mo).
	1.4301	304	0.07	17.0-19.5	8.0-10. 5	-	-	-	-	
	1.4404	316L	0.03	16.5-18.5	10.0-13.0	2.0-2.5	-	-	-	
	1.4401	316	0.07	16.5-18.5	10.0-13.0	2.0-2.5	-	-	-	
	1.4432	316L	0.03	16.5-18.5	10.5-13.0	2.5-3.0	-	-	-	
	1.4436	316	0.05	16.5-18.5	10.5-13.0	2.5-3.0	-	-	-	
	1.4541	321	0.08	17.0-19.0	9.0-12.0	-	-	-	Ti(2)	
	1.4571	316Ti	0.08	16.5-18.5	10.5-13.5	2.0-2.5	-	-	Ti(2)	
Higher alloy austenitic	1.4539	904L	0.02	19.0-21.0	24.0-26.0	4.0-5.0	1.2-2.0	-	-	Better corrosion resistance than simpler austenitic grades. Pitting and crevice corrosion resistance improves with increasing molybdenum and nitrogen content.
Super austenitic	1.4547	6% Mo alloys	0.02	19.5-20.5	17.5-18.5	6.0-7.0	0.5-1.0	0.18-0.25		6% Mo alloys were specifically developed for use in saline conditions.
	1.4529		0.02	19.0-21.0	24.0-26.0	6.0-7.0	0.5-1.5	0.15-0.25		Three grades (N08367/08925/08926) are also of similar composition to 1.4529.
Duplex	1.4362	2304	0.03	22.0-24.0	3.5-5.5	0.1-0.6		0.05-0.20	-	High strength and wear resistance with very good resistance to stress corrosion cracking. 1.4462 (2205) has better corrosion resistance than 1.4362 (2304). Super duplex alloys are suitable for seawater chloride levels. Grade 1.4501 contains 0.5-1.0% W.
	1.4462	2205	0.03	21.0-23.0	4.5-6.5	2.5-3.5	-	0.10-0.22	-	
Super Duplex	1.4507	25% Cr alloys	0.03	24.0-26.0	5.5-7.5	2.7-4.0	1.0-2.5	0.15-0.30	-	
	1.4410		0.03	24.0-26.0	6.0-8.0	3.0-4.5	-	0.20-0.35	-	
	1.4501		0.03	24.0-26.0	6.0-8.0	3.0-4.0	0.5-1.0	0.20-0.30	W	
High strength martensitic	1.4418	248SV	0.06	15.0-17.0	4.0-6.0	0.8-1.5	-	-	-	
Precipitation hardening (PH)	1.4542	17-4PH	0.07	15.0-17.0	3.0-5.0	0.6	3.0-5.0		Nb	

Notes:
(1) The popular name in most instances originates from the (now partly superseded) British Standards and AISI system
2) Titanium is added to stabilise carbon and improve corrosion performance in the heat affected zones of welds. However, except for very heavy section construction, the use of titanium stabilised steels has been superseded largely by the ready availability of the low carbon or 'L' grades in the table.

Information on Stainless Steels

A brief description of the nature and properties of stainless steels follows.

What is stainless steel?

"Stainless" is a term coined early in the development of these steels for cutlery applications. It was adopted as a generic name for these steels and now covers a wide range of steel types and grades for corrosion or oxidation resistant applications.

Stainless steels are iron alloys with a minimum of 10.5% chromium. Other alloying elements are added to enhance their structure and properties such as formability, strength and cryogenic toughness. These include metals such as nickel and molybdenum.

The main requirement for stainless steels is that they should be corrosion resistant for a specified application or environment. The selection of a particular "type" and "grade" of stainless steel must initially meet the corrosion resistance requirements. Additional mechanical or physical properties may also need to be considered to achieve the overall service performance requirements.

Families of stainless steels

There are several families of stainless steel: FERRITIC, MARTENSITIC, AUSTENITIC and DUPLEX. These names are derived from the crystal structure of the steels, which governs their metallurgical behaviour.

FERRITIC stainless steels are magnetic, have a low carbon content and contain chromium as the main alloying element, typically between 13% and 17%.. They are not hardenable by heat treatment.

MARTENSITIC stainless steels are magnetic, containing typically 12% chromium with a higher carbon content than the ferritic types. They are hardenable by quenching and tempering like plain carbon steels and find their main application in cutlery, aerospace and general engineering.

AUSTENITIC stainless steels are non-magnetic and, in addition to chromium typically around 18%, contain nickel. This enhances their corrosion resistance and modifies the structure from ferritic to austenitic. They are the most widely used group of stainless steels. They are not hardenable by heat treatment.

DUPLEX stainless steels are used where combinations of higher strength and corrosion resistance are needed. They have a mixed structure of austenite and ferrite, hence the term "duplex". They are not hardenable by heat treatment.

PRECIPITATION HARDENING stainless steels, like the martensitic types, can be strengthened (i.e. hardened) by heat treatment. The mechanism is metallurgically different from the process in the martensitic types. This means that either martensitic or austenitic precipitation hardening structures can be produced.

"Super" austenitic or "super" duplex grades have enhance pitting and crevice corrosion resistance compared with the ordinary austenitic or duplex types. This is due the further additions of chromium, molybdenum and nitrogen to these grades.

Why is stainless steel "stainless"?

The corrosion resistance of stainless steel arises from a "passive", chromium-rich, oxide film that forms naturally on the surface of the steel. Although extremely thin at 1-5 nanometres (i.e. 1-5 x 10^{-9} metres) thick, this protective film is strongly adherent, and chemically stable (i.e. passive) under conditions that provide sufficient oxygen to the surface.

The key to the durability of the corrosion resistance of stainless steels is that if the film is damaged it will normally self repair (provided there is sufficient oxygen available). In contrast to other steel types that suffer from "general" corrosion where large areas of the surface are affected, stainless steels in the "passive state" are normally resistant to this form of attack.

Stainless steels cannot be considered "indestructible", however. The passive state can be broken down under certain conditions and corrosion can result. This is why it is important to select carefully the appropriate grade for a particular application.

Corrosion and oxidation resistance of stainless steels

In general the corrosion and oxidation resistance of stainless steels improves as the chromium content increases. The addition of nickel to create the austenitic stainless steel grades strengthens the oxide film and raises their performance in more aggressive conditions. The addition of molybdenum to either the ferritic or austenitic stainless steels improves their resistance to pitting and crevice corrosion.

The austenitic stainless steels are resistant to the wide range of rural and industrial atmospheres encountered in the United Kingdom, resulting in extensive use in architectural, structural and street furniture applications. Their resistance to attack by acids, alkalis and other chemicals, has led to a wide use in the chemical and process plant industries.

The ferritic stainless steels are used in the more mildly corrosive environments, being often used in trim work and somewhat less demanding applications.

The corrosion resistance of martensitic stainless steels is similar to that of the ferritic types, whilst that of the precipitation hardening stainless steels is claimed to be similar to the 304 (1.4301) austenitic type stainless steel.

Duplex stainless steels are alloys designed to have improved localised corrosion resistance, specifically to stress corrosion cracking, crevice and pitting corrosion.

Corrosion attacks at the surface of a material. It is important therefore to ensure that the surface finish is suitable and that the surface is clean and uncontaminated (particularly from non-stainless steel contact). This enables the "inherent" corrosion resistance conferred by the additions of chromium, nickel, molybdenum etc. to be fully exploited.

Benefits of stainless steels

In economic terms stainless steels can compete with higher cost engineering metals and alloys based on nickel or titanium, whilst offering a range of corrosion resisting properties suitable for a wide range of applications. They have better strength than polymer products such as GRP. Stainless steels can be manipulated and fabricated using a wide range of commonly available engineering techniques and are fully "recyclable" at the end of their useful life.

In addition to their corrosion resistance, stainless steels also offer other useful properties, depending on their "family".

The austenitics, in the fully annealed heat-treated condition, are:

- Tough, with no brittle transition, down to cryogenic temperatures.

- Para-magnetic with relative magnetic permeabilities around 1.05.

The martensitic and precipitation hardening families are hardenable by heat treatment.

The duplex stainless steels are stronger than the austenitics in the annealed condition and so can be used in thinner sections to save weight and cost.

The ferritics are lower cost stainless steels.

Stainless steel and the environment

The main source of raw material for making stainless steels is re-cycled scrap metal. This re-cycling route has been established for many years and the economics of the stainless steel making industry depend on recycling. Over 90% of new stainless steel is produced from recycled scrap.

The steel is melted electrically and in most cases refined by using inert air distilled gases, such as argon. Great care is taken to minimise fume and dust emissions. Some plants are equipped to re-cycle dust into the steel making process.

Most of the steel processing consumable materials, including cooling water, lubricating oils, pickling acids and "inter-leaving" paper are re-cycled in the plant or by specialist contractors. Stainless steel fabricators and processors re-cycle their scrap arisings and in-process consumables, including "caking" pickling acid residues for re-cycling.

As stainless steels are corrosion resistant alloys their life expectancy is usually long. A minimum of maintenance is needed and so, although more expensive initially, they offer attractive "life-cycle cost" benefits over alternatives such as carbon steels. Stainless steel components may be re-usable and are fully recyclable at the end of life of a particular plant installation.

Stainless steels are easily cleaned and so an obvious choice for food and beverage manufacturing industries and catering equipment. There are no proven health risks from the normal use of stainless steels. The possible risks from alloying elements such as nickel and chromium are under constant review by experts.

More about stainless steel

To find out more about stainless steels, their selection, fabrication, performance and application, then visit "On Line Technical Advice" of the "Technical Information" section of The British Stainless Steel Association [BSSA] website at http://www.bssa.org.uk/index.htm.

This provides the opportunity to search for technical advice "articles", by selecting from menus of

Technical Area
Technical Issue

Alternatively, free-text questions can be entered.

Further information may also be found at http://www.nidi.org/ and http://www.steel-sci.org/.

REFERENCES

REFERENCES

[i] ANSI/API. **API Standard 650 Welded steel tanks for oil storage.** ANSI/API, 9th Ed, 1993.

[ii] ASME. **Boiler and pressure vessel code, Section VIII Pressure Vessels.** ASME, 1995.

[iii] AWS. **D1.6:1999 Structural welding code.** AWI, 1999.

[iv] BRITISH STANDARDS INSTITUTION. **BS 1564:1975/1983: Specification for pressed steel sectional rectangular tanks**. BSI, 1975/1983.

[v] BRITISH STANDARDS INSTITUTION. **BS 2654 Specification for manufacture of vertical steel welded non-refrigerated storage tanks with butt-welded shells for the petroleum industry.** BSI, 1989.

[vi] BRITISH STANDARDS INSTITUTION. **BS EN ISO 3506:1998 – Mechanical properties of corrosion-resistant stainless steel fasteners.** BSI, 1998.

[vii] BRITISH STANDARDS INSTITUTION. **BS 8010 Code of practice for pipelines Part 2, Section 2.8 Steel for oil and gas.** BSI, 1992.

[viii] BRITISH STANDARDS INSTITUTION. **BS EN 287-1:1992: Approval testing of welders for fusion welding. Steels.** BSI, 1992.

[ix] BRITISH STANDARDS INSTITUTION. **BS EN 288-1 to 3 and 5 to 9:1992 to 1999: Specification and approval of welding procedures for metallic materials.** BSI, 1992 – 1999.

[x] BRITISH STANDARDS INSTITUTION. **BS EN 970 Non-destructive examination of fusion welds. Visual examination**. BSI, 1997.

[xi] BRITISH STANDARDS INSTITUTION. **BS EN 1011-3:2000 Welding. Recommendations for welding of metallic materials. Arc welding of stainless steels.** BSI, 2000.

[xii] BRITISH STANDARDS INSTITUTION. **BS EN 10088 Stainless steels. List of stainless steels.** BSI, 1995.

[xiii] BRITISH STANDARDS INSTITUTION. **BS EN 25817 Arc welded joints in steel - guidance on**

quality levels for imperfections. BSI, 1992.

xiv BRITISH STANDARDS INSTITUTION. **BS PD 5500 Specification for unfired fusion welded pressure vessels.** BSI, 2000.

xv BRITISH STANDARDS INSTITUTION. **CP 2010 Code of practice for pipelines Part 2 Design and construction of steel pipelines in land.** BSI, 1970.

xvi BRITISH STANDARDS INSTITUTION. **DD ENV 1090-6 Execution of steel structures; Supplementary rules for stainless steels.** BSI, 2001.

xvii BRITISH STANDARDS INSTITUTION. **ENV 1993-1-4 Eurocode 3: Design of steel structures. Part 1 - 4: 1996 General rules - Supplementary rules for stainless steels.** BSI, 1996.

xviii BURGAN, B A. **Concise guide to the structural design of stainless steel.** The Steel Construction Institute, SCI-P-123, Second Edition, 1993.

xix THE STEEL CONSTRUCTION INSTITUTE. **Applications for stainless steel in the water industry.** Water Industry Guidance Note IGN 4-25-02. SCI, 1999.

xx CHUNG, K F, BADDOO, N R and BURGAN, B A. **Section property and member capacity tables for cold-formed stainless steel.** The Steel Construction Institute, SCI-P-152, 1995.

xxi AMERICAN SOCIETY OF CIVIL ENGINEERS. **LRFD Specification for the design of cold-formed stainless steel structural members.** ASCE, 1991.

xxii BADDOO, N R. **Design of stainless steel fixings and ancillary components.** The Steel Construction Institute, SCI-P-119, 1993.

xxiii STAINLESS STEEL ADVISORY SERVICE. **Paint Coating of Stainless Steel** Information Sheet 5.80, SSAS,2001.

xxiv STAINLESS STEEL ADVISORY SERVICE. **Corrosion Barriers for Thermally Insulated Stainless Steel** Information Sheet 5.81, SSAS,2001.

xxv NICKEL DEVELOPMENT INSTITUTE. **Stainless steel for potable water treatment plants**. Technical Series, 10087, NiDI, 1999.

xxvi STAINLESS STEEL ADVISORY SERVICE. **Corrosion of stainless steels in supply (drinking) and**

waste (sewage) water systems. Information Sheet 4.92. SSAS, 2000.

[xxvii] NICKEL DEVELOPMENT INSTITUTE. **Stainless steel plumbing.** Reference Book Series, 11019, NiDI, 1997.

[xxviii] BRITISH STANDARDS INSTITUTION. **BS 4127 Specification for light gauge stainless steel tubes, primarily for water applications.** BSI, 1994. To be replaced by BS EN 10312 – in prep.

[xxix] BRITISH STANDARDS INSTITUTION. **BS 3605-1 Austenitic stainless steel pipes and tubes for pressure purposes. Specification for seamless tubes.** BSI, 1991.

[xxx] BRITISH STANDARDS INSTITUTION. **BS 3605-2:1992 Austenitic stainless steel pipes and tubes for pressure purposes. Specification for longitudinally welded tubes.** BSI, 1992.

[xxxi] BRITISH STANDARDS INSTITUTION. **BS 1864 Specification for stainless steel milk pipes and fittings (recessed ring joint type).** BSI, 1966.

[xxxii] BRITISH STANDARDS INSTITUTION. **BS 4825-1 Stainless steel tubes and fittings for the food industry and other hygienic applications. Specification for tubes.** BSI, 1991.

[xxxiii] ASTM. **A 380- 99 Cleaning, descaling and passivation of stainless steel parts, equipment and systems.** ASTM, 1999.

[xxxiv] SCHWENK, W. British Corrosion Journal, Vol. 26, No 4 pp 245-9, 1991.