BSSA

BSSA
British Stainless Steel Association

UNDERSTANDING STAINLESS STEEL

This book will help everyone involved with buying, selling, specifying and working with stainless steel to understand this versatile material.

Published February 2009

By

British Stainless Steel Association

Broomgrove
59 Clarkehouse Road
Sheffield S10 2LE

Telephone: +44 (0) 114 267 1260
Fax: +44 (0) 114 266 1252
Email: enquiry@bssa.org.uk
Website: www.bssa.org.uk

ISBN 978-0-9561897-0-7

About the British Stainless Steel Association

The British Stainless Steel Association is a membership based organisation whose purpose is to promote the greater use of stainless steel in the UK and Ireland. Its strength lies in the breadth of its membership with companies from all sectors of the industry and all stages of the supply chain.

Originally formed as an association of stainless steel fabricators, the BSSA has steadily increased its scope of membership and range of activities over the years. In 2000, the BSSA was reformed and a small full-time staff was established to allow its services to be developed further. At the same time the Stainless Steel Advisory Service was launched which now operates as an integral part of the BSSA.

The BSSA has four principal areas of activity:

- Providing help and advice both through the Stainless Steel Advisory Service and via the website: **www.bssa.org.uk**;
- Training and education, including Starter Workshops, the Stainless Steel Specialist Course, open seminars and in-company bespoke workshops;
- Market development initiatives in sectors such as Architecture, Building and Construction, Water and Energy;
- Industry events, including forums, seminars, conferences and social functions.

The BSSA also provides benefits to its members through its involvement with other partner organisations such as the International Stainless Steel Forum (ISSF) and the European Stainless Steel Development Association (Euro Inox). It also works closely with other UK based organisations including UK Steel, the Steel Construction Institute, NAMTEC and the Metals Forum.

About the Author

Alan Harrison graduated in Metallurgy from Sheffield University in 1975. Since then he has been involved in the Sheffield steel industry. From 1975 to 1989 he was a metallurgist at British Steel River Don Works later Sheffield Forgemasters. His involvement in stainless steel began with a move in 1989 to British Steel Stainless later Avesta Sheffield, Avesta Polarit and Outokumpu Stainless. After excursions into market research and IT, he returned to the metallurgical world in 2006 on becoming the Technical Advisor to the BSSA.

Introduction

Understanding Stainless Steel

The idea for this book grew out of a series of "Starter Workshops" run by the British Stainless Steel Association (BSSA). These 1-day seminars are designed for those who have little or no knowledge of stainless steel or who need a refresher in the basics. "Understanding Stainless Steel" complements the "Starter Workshops" and will help those involved in specifying, designing, buying, selling or fabricating this versatile product.

I hope that you will find that the book increases your knowledge of a material which is becoming increasingly important in the developed and developing world.

This book is dedicated to the thousands and men and women who have made the city of Sheffield a synonym for high quality steel. Although the "city of a thousand fires" has fewer steel companies than in its heyday it is still a significant producer of stainless and other high grade steels which underpins the whole economy. After all it was a Sheffielder who invented stainless steel.

I am grateful to my colleagues at the BSSA, particularly David Humphreys who was instrumental in developing the "Starter Workshops", and from BSSA Members who made helpful suggestions with the content of the book. A special thank you to my daughter, Joy, who read and commented on the initial draft.

Acknowledgments

I would particularly like to thank the following organisations for providing images, diagrams and assistance with the content of the Guide:

BSSA Marketing and Technical Committee
ArcelorMittal Stainless
Australian Stainless Steel Development Association
ELG Haniel
G-Tex Stainless
Jordan Manufacturing Ltd
Judith Duddle
Nickel Institute
Outokumpu Stainless
Pland Stainless
Rimex Metals
Stainless Restoration
Valbruna UK Ltd

Contents

Contents

Contents

Chapter 1 - The World of Stainless Steel

Our modern world would be unthinkable without stainless steel – or more accurately "steels". As we shall see, "stainless steel" covers a wide range of materials each suited to a particular set of conditions.

The following are a typical but by no means exhaustive list of applications:

Transport

Architecture

Civil Engineering

Chapter 3 - A Little Metallurgy

Basic Definitions

Most of these definitions would be scorned by a "proper" chemist or metallurgist but they will do for our purposes.

Atom – The basic building block of matter. Atoms are very small about 0.1 nanometres. This means that you could pack 10 million atoms on a line 1mm long.

Element – A chemical that contains only one sort of atom. Familiar elements are oxygen, silicon, iron, aluminium, sulphur, nitrogen.

Chemical Symbol – A shorthand way of denoting an element. Either one or two letters are used for each element. For example:

Fe = Iron (Fe from Latin ferrum)
Cr = Chromium
Mo = Molybdenum
Mn = Manganese
S = Sulphur
C = Carbon
Ni = Nickel
Ti = Titanium
Si = Silicon
N = Nitrogen

A fuller list can be found in chapter 15.

Metal – An element that is usually shiny, easy to form, conducts heat and electricity well. Iron, copper, aluminium, nickel, lead, zinc and chromium are metals. Metals normally exist as crystals or grains.

Crystal – A crystalline material is one in which the atoms are arranged in a regular 3 dimensional pattern. This does not mean that metals show a regular shape on a large scale like a quartz crystal.

Compound – A combination of two or more elements which forms a different material to any of the constituent elements. A well known compound is salt or sodium chloride. This is made from sodium which is a soft highly reactive metal and chlorine which is a poisonous green gas. Sodium chloride is a white, crystalline solid.

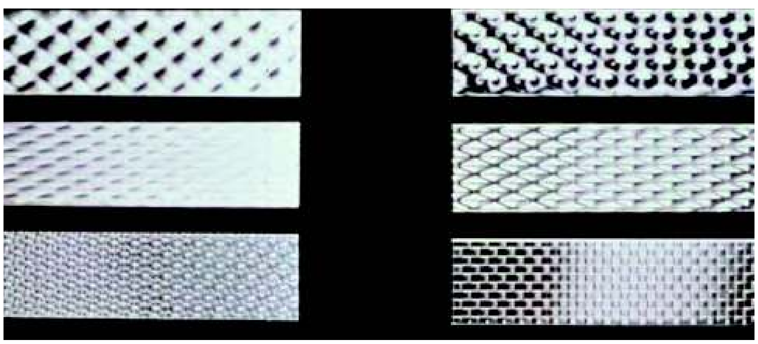
Molecule – The smallest part in which a compound can exist. A molecule of sodium chloride consists of one atom of sodium and one of chlorine.

Chapter 5 - Why Use a Stainless Steel

Obviously, stainless steel is mostly used for its corrosion resistance. However, there are other properties which can be equally important. These include:

- **Attractive appearance, wide range of surface finishes**

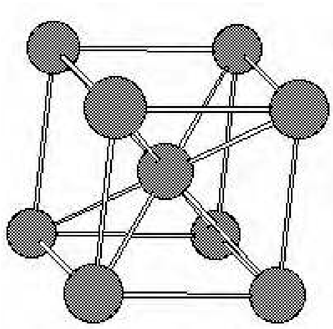
There are mill finishes, bright polished, dull polished, patterned, coloured and a virtually unlimited combination of these types to give designers a wide choice of final appearance.



Chapter 6 - The Structure Stainless Steel

This chapter is about as technical as it gets, so if you get through this everything else will be plain sailing!

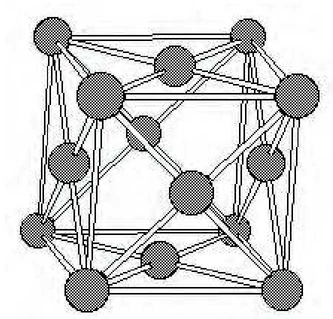
You will recall that ordinary steel is an alloy of iron and carbon. At normal temperatures, iron atoms are arranged in a pattern or lattice as shown below:



This is called a Body Centred Cubic (BCC) structure for fairly obvious reasons. There is an atom at each corner of a cube and one in the middle. The arrangement of atoms is called a lattice. The atoms of carbon are smaller and have to fit in as best they can within the structure. In iron and steel this structure is also called ferritic.

The ferritic structure is magnetic.

When ordinary steels are heated up to about 900° C, the atomic structure changes to this pattern:



This is called Face Centred Cubic (FCC). There is one atom at each corner and one in the middle of each face. This structure is also called austenitic.

The austenitic structure is non-magnetic.

Chapter 7 - Types of Stainless Steel

The five basic types described in chapter 6 are used in approximately the following proportions:

- Austenitic 65 - 70%
- Ferritic 20 - 25%%
- Martensitic about 7%
- Duplex about 1%
- Precipitation Hardening about 2%

PROPERTIES OF AUSTENITIC TYPE

Pros	Cons	Typical Applications
Easy to produce Formable – stretch forming Weldable in thick sections Low temperature toughness Oxidation resistance Non-magnetic Strengthened by cold work Can be surface hardened High alloy grades giving high level of corrosion resistance	Subject to big price swings due to nickel volatility High alloy grades more expensive Not heat treatable in bulk Low thermal conductivity High thermal expansion Difficult to machine	Sinks, saucepans, cutlery, cladding, handrails, roofing, catering surfaces, chemical, pharmaceutical, pressure vessels, food processing, oil and gas, street furniture, sanitary equipment, hospital equipment, MRI scanners, building products e.g. wall ties, furnaces, electrical energy, cryogenic storage vessels, springs, rail carriages, high spec exhaust systems, automotive structural (under development), process piping, medical devices, water tubing, nuclear processing, yacht trim

There is also some logic in the EN Number:

1.40xx and 1.41xx – ferritic and martensitic stainless steels
1.43xx – stainless steel without Mo (both austenitic and duplex)
1.44xx – stainless steel with Mo (both austenitic and duplex)
1.45xx – stainless steels with special additions (ferritic, austenitic and duplex)
1.47xx – ferritic heat resisting steels
1.48xx – austenitic heat resisting steels
1.49xx – creep resisting steels

The following tables show some typical grades of each of the 5 main types.

SOME EXAMPLES OF AUSTENITIC GRADES

EN name	EN number	Chemical Composition from EN 10088/EN 10095 (single values are maximum)				
		C	Cr	Mo	NI	Others
X12CrMnNi17-7-5	1.4372	0.15	16.0/18.0		3.5/5.5	Mn 5.5/7.5
X10CrNi18-8	1.4310	0.05/0.15	16.0/19.0		6.0/9.5	
X5CrNi18-10	1.4301	0.07	17.5/19.5		8.0/10.5	
X2CrNi18-9	1.4307	0.030	17.5/19.5		8.0/10.5	
X8CrNiS18-9	1.4305	0.10	17.0/19.0		8.0/10.0	S: 0.15/0.35 Cu:1.00
X5CrNiMo17-12-2	1.4401	0.07	16.5/18.5	2.00/2.50	10.0/13.0	
X2CrNiMo17-12-2	1.4404	0.030	16.5/18.5	2.00/2.50	10.0/13.0	
X8CrNi25-21	1.4845	0.10	24.0/26.0		19.0/22.0	
X1NiCrMoCu25-20-5	1.4539	0.020	19.0/21.0	4.0/5.0	24.0/26.0	
X1NiCrMoCuN20-18-7	1.4547	0.020	19.5/20.5	6.0/7.0	17.5/18.5	N 0.18/0.25

EN number	'Old' BS no.	UNS number	Common name	Applications
1.4372	-	S20100	201	Lighting columns
1.4310	301S21	S30100	301	Springs
1.4301	304S31	S30400	304	Sinks
1.4307	304S11	S30403	304L	Pressure vessels
1.4305	303S31	S30300	303	Free machined components
1.4401	316S31	S31600	316	Architectural cladding
1.4404	316S11	S31603	316L	Pharmaceuticals, oil and gas
1.4845	310S24	S31000	310	High temperature furnace
1.4539	904S13	N08904	904L	Sulphuric acid service
1.4547	-	S31254	254SMO	Severely corrosive environments, desalination, pulp and paper

Chapter 9 - Magnetic Properties of Stainless Steel

Now that we have covered the basic structure and properties of stainless steels, it is worth spending a little time on this subject. This is particularly important as there is a lot of mis-information around.

"A magnet will not stick to 304 stainless steel but it will to type 430 or to any other inferior material".

Although the statement is generally correct, the truth is rather more complex.

Recap from Chapter 6:

Steel Structure	Magnetic Properties
Ferritic (Body Centred Cubic)	Magnetic
Martensitic (Body Centred Tetragonal)	Magnetic
Austenitic (Face Centred Cubic)	Non-Magnetic
Duplex (Mixed Austenitic/Ferritic)	Magnetic

Austenitic stainless steels such as type 1.4301 (304), 1.4401 (316) are nominally non-magnetic because the austenite structure is non-magnetic. However, there are two reasons why an austenitic stainless steel can have some degree of magnetic response.

Effect of Ferrite

All austenitic stainless steels contain a small amount of ferrite. Usually, this is not enough to attract a normal magnet. However, if the balance of elements in the steel favours the ferritic end of the spectrum, it is possible for the amount of ferrite to be sufficient to cause a significant magnetic response. Also, some types of product are deliberately balanced to have a significant amount of ferrite. Castings are in this category and normally have about 10% ferrite. Welding can also induce a greater magnetic response in the melted zone where ferrite is produced in greater quantities than in the parent material.

Chapter 10 - The Testing of Stainless Steels

In this chapter, we will take a brief look at the tests that are carried out on stainless steels before being released into the supply chain. The information will help you interpret the test certificates which are often supplied with the material.

Unfortunately, there is no agreed format or content for test certificates so it is sometimes a little difficult to find all the information you might want.

Before looking at an actual test certificate, we need to understand what kind of information is being presented.

All steel products are tested to ensure conformance with recognised standards. A typical test certificate always shows:

- Standards and grades
- Product description (dimensions, finish etc)
- Chemical composition
- Room temperature tensile test properties
- Hardness

It may show:

- Tolerance standard
- Impact toughness
- High temperature tensile test properties
- Corrosion tests
- NDT (Non Destructive Tests) e.g. ultrasonic, dye penetrant, magnetic particle inspection, eddy current testing

Standards and Grades

The table shows some common examples of standards and grades.

Standard	Products Covered	Common Grades
EN 10088-2	Flat Products	1.4301 1.4307 1.4401 1.4404
EN 10088-3	Long Products	1.4301 1.4307 1.4401 1.4404
EN 10095	Heat Resisting Steels	1.4845 1.4835
ASTM A240	Flat Products	304 304L 316 316L
ASTM A276	Long Products	304 304L 316 316L

Chapter 14 - The Ingredients of Stainless Steel

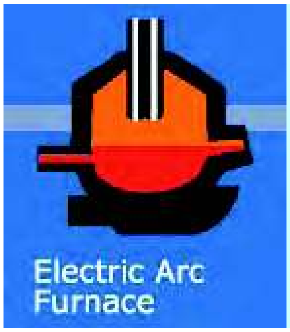
The following table lists the different elements used in stainless steels and their effects on properties:

Element	Symbol	Approximate Content Range %	Properties Affected	Grades Showing Effect of Element
Chromium	Cr	10.5 – 30	Cr is the essential ingredient of stainless steel. It improves: Pitting corrosion resistance Crevice corrosion resistance General corrosion resistance High temperature oxidation resistance	All stainless steels
Nickel	Ni	0 – 37	Ni is used to make the austenitic structure stable at normal temperatures. The austenitic structure improves the formability and weldability of stainless steels. Low Ni for stretch forming High Ni for deep drawing High Ni austenitic stainless steels are very resistant to stress corrosion cracking. Ni also improves the high temperature oxidation.	1.4301 8% Ni 1.4301 9% Ni 1.4303 (305) 1.4539 (904L) 1.4547 1.4529 1.4845 (310)
Molybdenum	Mo	0 – 6	Mo improves: Pitting corrosion resistance Crevice corrosion resistance General corrosion resistance It may be detrimental in some high temperature applications It gives a small increase in strength	1.4521 (444) 1.4401 (316) 1.4404 (316L) 1.4462 (2205) 1.4539 (904L) 1.4547 1.4529

Chapter 15 - The Manufacture of Stainless Steel

Flat Products

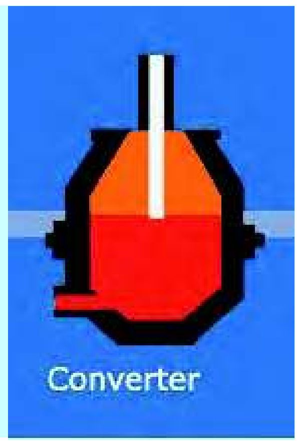
The process route shown is for a standard austenitic stainless steel.

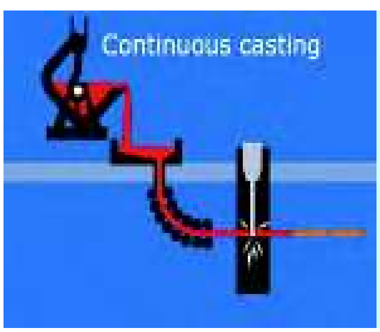


All stainless steel starts with melting in an electric arc furnace (EAF).
Typical capacity 100-150 tonnes.
Scrap accounts for 60-70% of a new melt or cast.
Temperatures in the arc furnace are around 1500°C.

The molten steel is transferred to a converter usually an AOD vessel. (Argon oxygen decarburisation). Here the carbon is blown out using oxygen. The invention of this process in 1954 and its subsequent development led to a step change in the cost of production of stainless steels due to the efficient reduction in carbon levels particularly for the low carbon "L" grades.

Alloying elements are added to bring the cast into the required composition range.





The molten steel is then poured vertically into a mould. As the steel solidifies it is formed by a series of rolls into a horizontal slab typically 1000 – 2000 mm wide by 100 - 300 mm thick. The slab is then flame cut into lengths suitable for hot rolling. Slab grinding may also take place to make the resulting hot rolled surface better.

The invention of the continuous casting (concast) process was another major step in reducing the cost of production.

Chapter 21 - Common Standards for Stainless Steel

The European system of standards is extensive. One of the principles of the system is that there is a parent standard for each main product form and a number of referenced standards which deal with tolerances, test methods etc. The following table summarises the referenced standards for the standards relating to stainless flat, long and tube products:

Standard	Product Form	Related Standards	Subject
EN 10088-2	Flat	EN 10088-2	Chemical Compositions
		EN 10088-2	Mechanical properties
		EN 10258	Tolerances for narrow cold rolled strip
		EN 10259	Tolerances for wide cold rolled strip/sheet/coil
		EN 10051	Tolerances for hot rolled coil/sheet
		EN 10029	Tolerances for quarto plate
		ISO 9444	Tolerances for hot rolled coil/sheet. (To supersede EN 10051)
		ISO 9445	Tolerances for all cold rolled products (To supersede EN 10258/9)
		ISO 18286	Tolerances for quarto plate (To supersede EN 10029)
		EN 10079	Definition of product forms
		EN 10002	Tensile test methods
		EN 10045	Impact test methods
		EN 10163-2	Surface condition of hot rolled flat products
		EN 10168	Inspection documents
		EN 10204	Types of inspection documents
		EN 10307	Ultrasonic testing of flat products
		EN ISO 377	Test piece sampling
		EN ISO 3651-2	Intergranular corrosion testing
		EN ISO 6506-1	Brinell hardness testing
		EN ISO 6507-1	Vickers hardness testing
		EN ISO 6508-1	Rockwell hardness testing
		EN ISO 14284	Sampling for chemical composition testing