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By

British Stainless Steel Association

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Preface to the 2nd Edition

This edition has been prepared to coincide with the centenary of the invention of one of the earliest stainless steel grades by Sheffield metallurgist Harry Brearley in 1913. This edition corrects some errors and omissions from the first edition. Updates on grades and surface treatments are also included. Particular thanks to Andy Backhouse of Outokumpu Stainless for providing proof reading and helpful suggestions for this edition. Also to John Swain of Anopol for the section on electropolishing.

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 of 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.

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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 14.

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.

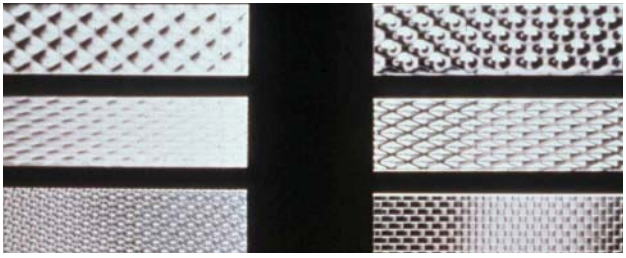
Molecule – The smallest part in which a compound can exist. A molecule of sodium chloride consists of one atom of sodium and one of chlorine.

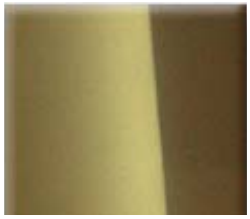
Chapter 5 - Why Use a Stainless Steel?

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, electropolished, patterned, bead blasted, coloured and a virtually unlimited combination of these types to give designers a wide choice of final appearance.





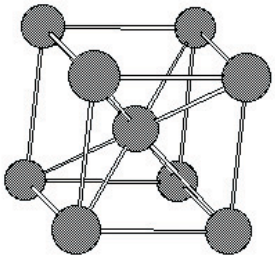
- **Ease of cleaning, hygienic - no bug traps**

It has been demonstrated in scientific tests that stainless steel can be cleaned efficiently even after prolonged use and normal wear and tear. This has led to it being a material of choice for the catering and hospital sectors.

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!

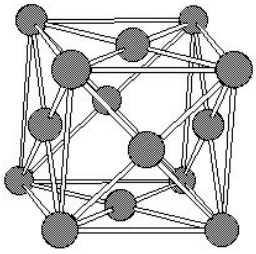
You will recall that ordinary steel is an alloy of iron and carbon. At normal temperatures, iron atoms are arranged in a pattern or lattice as shown below:



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 1-3%
- Precipitation Hardening about 2%

PROPERTIES OF AUSTENITIC TYPE

Pros	Cons	Typical Applications
Standard grades are 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,duplex and precipitation hardening)
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.

It should be noted that the equivalent grades in other systems are the *nearest* in composition. There can be minor differences in the ranges of some elements.

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	
X2CrNiMnMoNNb21–16–5–3	1.3964	0.06	20.5/23.5	1.5/3.0	11.5/13.5	Mn 4.0/6.0 N 0.2/0.4 Nb 0.1/0.3 V 0.1/0.3
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 Cu 0.50/1.00
X1NiCrMoCuN25-20-7	1.4529	0.020	19.0/21.0	6.0/7.0	24.0/26.0	N 0.15/0.25 Cu 0.50/1.00

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.

This is illustrated by a quote from a stainless steel fabricator's website:

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

The statement contains several errors, and the full 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.

The basic information on chemical composition and mechanical properties can be found on all test certificates. However, there are significant variations in the format of test certificates among producers. There are also variations in the "non-mandatory" information.

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 (some producers show target range and/or residual elements)
- Room temperature tensile test properties
- Hardness

It may show:

- Dimensional Tolerance standard
- Impact toughness at room temperature and/or sub-zero temperature
- High temperature tensile test properties
- Corrosion tests
- Results of Metallographic examination eg cleanness, grain size, structure assessment
- NDT (Non Destructive Tests) e.g. visual, 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