



## CHEMICAL AND PROCESS PLANT





# **CHEMICAL AND PROCESS PLANT**

**a guide to the selection of  
engineering materials**

**LEE S. EVANS, BSc, CEng, FIM, FICorrT**

**HUTCHINSON**

*London Melbourne Sydney Auckland Johannesburg*

Hutchinson & Co. (Publishers) Ltd.

An imprint of the Hutchinson Publishing Group

24 Highbury Crescent, London N5 1RX

Hutchinson Group (Australia) Pty Ltd

30-32 Cremorne Street, Richmond South, Victoria 3121

PO Box 151, Broadway, New South Wales 2007

Hutchinson Group (NZ) Ltd

32-34 View Road, PO Box 40-086, Glenfield, Auckland 10

Hutchinson Group (SA) (Pty) Ltd

PO Box 337, Bergvlei 2012, South Africa

First published 1974 as *Selecting Engineering Materials  
for Chemical and Process Plants* by Business Books Ltd

Second edition published by Hutchinson 1980

© Lee S. Evans 1974 and 1980

Illustrations © Hutchinson & Co. (Publishers) Ltd

Printed in Great Britain by The Anchor Press Ltd

and bound by Wm Brendon & Son Ltd,

both of Tiptree, Essex

**British Library Cataloguing in Publication Data**

Evans, Lee Stanley

Chemical and process plant. — 2nd ed.

1. Chemical plants — Equipment and supplies —  
Handbooks, manuals, etc.

I. Title II. Selecting engineering materials  
for chemical and process plant

660.2'82 TP157

ISBN 0 09 142790 8

# Contents

<i>List of figures and tables</i>	8
<i>Introduction to the first edition</i>	11
<i>Introduction to the second edition</i>	12
<i>Acknowledgements</i>	13
<b>1 Carbon and low alloy steels</b>	<b>15</b>
Low-carbon steels (mild steel) — Limitations — Corrosion resistance — High temperatures — High stresses — Low temperatures — Fracture mechanics — High-carbon steels — Low-carbon low alloy steels — Mechanical properties and corrosion resistance — Oxidation resistance and creep strength — Low temperature ductility — High-carbon low alloy steels — References	
<b>2 High alloy steels</b>	<b>34</b>
Chromium steels (400 series) — Chromium/nickel austenitic steels (300 series) — Precipitation-hardening stainless steels — Duplex ferritic/austenitic steels — Maraging steels — Properties and applications — Corrosion resistance — Oxidation resistance — Creep strength at elevated temperatures — Mechanical properties at low temperatures — References	
<b>3 Pressure vessel design codes</b>	<b>52</b>
Definitions of pressure vessels — Specifications of materials — Criteria for design stresses — Effect of design criteria on costs — References	

<b>4</b>	<b>Cast iron</b>	<b>58</b>
	General description — Types of cast iron — Specific applicational requirements — References	
<b>5</b>	<b>Nickel and nickel alloys</b>	<b>70</b>
	Corrosion-resistant alloys — Heat-resistant alloys — References	
<b>6</b>	<b>Copper and copper alloys</b>	<b>76</b>
	Principal alloys: coppers, brasses, bronzes, cupro-nickels — Corrosion resistance — Fabrication — References	
<b>7</b>	<b>Lead and lead alloys</b>	<b>85</b>
	Lead specifications — Mechanical properties — Forms available — Fabrication techniques — References	
<b>8</b>	<b>Aluminium and aluminium alloys</b>	<b>89</b>
	Aluminium alloy compositions — Effect of temperature on properties — Fabrication — Corrosion resistance — Applications — References	
<b>9</b>	<b>New metals and precious metals</b>	<b>100</b>
	Titanium — Tantalum — Zirconium — Platinum — Gold — Silver — Fabrication — References	
<b>10</b>	<b>Carbon, graphite and glass</b>	<b>112</b>
	Carbon and graphite — Types of glass — Glass process equipment — Glass-lined steel and cast iron — References	
<b>11</b>	<b>Cements, bricks and tiles</b>	<b>118</b>
	Hydraulic cements — Brick- and tile-lined vessels and floors — References	
<b>12</b>	<b>Plastics — thermoplastics</b>	<b>123</b>
	Corrosion resistance — Mechanical properties — Raw material and conversion costs — Polyolefins — PVC [poly (vinyl chloride)] — Acrylonitrile-butadiene-styrene (ABS) — Fluorinated plastics — Acrylics — Nylon (polyamide) — Other engineering plastics — References	
<b>13</b>	<b>Plastics — thermosetting</b>	<b>142</b>
	Phenolic resins — Polyester resins — Epoxy resins — Furane resins — Vinyl ester (Derakane) — References	

<b>14</b>	<b>Rubber and plastic linings — sheet and film</b>	<b>148</b>
	Rubber linings — Plastic linings — References	
<b>15</b>	<b>Metallic coatings</b>	<b>154</b>
	Electro-deposition — Dip coatings — Sprayed coatings — Diffusion coatings — References	
<b>16</b>	<b>Organic coatings</b>	<b>161</b>
	Paints for prevention of corrosion by atmospheric pollution — Chemical-resistant paints — Coatings for immersion in process liquors — References	
<b>17</b>	<b>Costs of materials</b>	<b>170</b>
	Metal plate and castings — Plastics — Metal and plastic pipe — References	
<b>Appendix A</b>	<b>Trade names of thermoplastics</b>	<b>177</b>
<b>Appendix B</b>	<b>Trade names of thermosetting resins</b>	<b>180</b>
<b>Appendix C</b>	<b>Addresses of plastics manufacturers</b>	<b>181</b>
<i>Index</i>		<b>183</b>



# List of figures and tables

## *Figures*

1	Comparison of high-temperature properties of typical carbon/manganese and low alloy pressure vessel steels	20
2	Typical Charpy impact test curve for low-carbon and carbon/manganese steels	21
3	Typical effect of material thickness on minimum design temperatures	23
4	Effect of temperature on corrosion rates of steels in crude oil containing 1.5% sulphur	28
5	Typical proof stress and creep strength curves for carbon, low alloy and austenitic steels	53

## *Tables*

1	Typical types and applications of low alloy steels	26
2	Maximum temperatures for use in oxidizing conditions for steels of various chromium content	29
3	Effect of alloying on creep properties	30
4	Typical operating limits for superheater tubes in power station boilers	30
5	Wrought stainless and heat-resisting steels: AISI types	35
6	Chromium stainless and heat-resisting steels: approximate national equivalents	36
7	Chromium nickel austenitic stainless and heat-resisting steels: approximate national equivalents	37
8	Cast corrosion-resisting high alloy steels	38
9	Cast heat-resistant high alloy steels	38
10	Ferritic low interstitial steels	40
11	Austenitic stainless steels with very high alloy contents	42
12	Compositions of typical proprietary precipitation-hardening stainless steels	44

13	Compositions of duplex ferritic/austenitic steels	44
14	Stainless maraging steels	45
15	Cast alloys for furnace coils, etc. — creep strength	48
16	Pressure vessel codes in various countries (ferritic steels)	54
17	Illustration of design code criteria for a typical low alloy steel	55
18	Design stresses at room temperature of various steels by different pressure vessel codes	56
19	Typical mechanical properties of the various types of cast iron	60
20	Effect of section thickness on strength of grey iron castings	61
21	Composition and mechanical properties of the four main types of white iron	61
22	Austenitic cast irons — flake graphite grades	63
23	Austenitic cast irons — spheroidal graphite grades	64
24	Suggested maximum working stresses for various grades of cast iron up to 600°C	68
25	Rods and electrodes for fusion welding of cast iron	68
26	Filler rods for non-fusion welding of cast iron	68
27	Nickel-based corrosion-resistant alloys	71
28	Nickel-based heat-resistant alloys	74
29	Classification system used in USA for copper alloys	77
30	Effect of impurities and alloying elements on electrical conductivity of copper	77
31	Composition and mechanical properties of commonly used brasses	78
32	Copper alloys commonly used for condenser tubes	79
33	Tin bronzes and gunmetals	80
34	Aluminium and manganese bronzes	81
35	Cupro-nickel alloys: mechanical properties of wrought alloys in annealed condition	83
36	Maximum stresses in pipe wall of lead and alloys for life of 5 to 10 years	86
37	Fatigue strength of lead alloys	87
38	American aluminium alloys	90
39	Effect of degree of purity on mechanical properties of aluminium	91
40	Non-heat-treatable aluminium alloys: typical mechanical properties in the fully annealed condition	91
41	Heat-treatable aluminium alloys: effect of heat treatment on mechanical properties	92
42	Casting alloys recommended for corrosive applications	93
43	Effect of elevated temperatures on tensile strength of wrought and cast aluminium alloys	94

44	Data showing alloys available for cryogenic applications	98
45	Relative costs of titanium, zirconium, tantalum and precious metals	101
46	Physical and mechanical properties of titanium, tantalum and zirconium	101
47	Mechanical properties of titanium and titanium alloys	102
48	Effect of elevated temperatures on tensile strength of titanium and titanium alloys	103
49	Comparative corrosion resistance of tantalum and platinum	106
50	Physical and mechanical properties of precious metals	109
51	Physical properties of carbon and graphite	112
52	Comparative chemical resistance of bedding and jointing cements for brick and tile linings	121
53	Typical physical and mechanical properties of thermoplastics	125
54	Hydrostatic design pressures for thermoplastic pipes at temperatures up to 120°C	125
55	Relative costs of thermoplastic moulding powders	126
56	Effect of density on stiffness of polyethylene polymers	127
57	Properties of polyethylene dependent on molecular weight and degree of crystallinity	128
58	Properties of fluorinated plastics	135
59	Comparative properties of the main types of nylon	138
60	Properties of engineering plastics	139
61	Mechanical properties of phenolic/asbestos laminates	143
62	Physical and mechanical properties of glass-fibre-reinforced resins	144
63	Relative costs of metal plate and castings	171
64	Ratios of equipment costs and material costs	172
65	Relative costs of plastic moulding powders and resins	172
66	Relative costs of metallic and non-metallic pipe with a guide to pressure and temperature operating limits	174
67	Dimensions of American schedule pipes	175

# Introduction to the first edition

The range of materials from which chemical engineers, and others who are concerned with the specification and construction of process plant, can choose, is now very wide and varied. The main purpose of this book is to draw attention to all these materials so that none are overlooked.

The main physical, mechanical and chemical properties and basic costs of each material are given so that an initial appraisal can be made of suitability for a particular project. Many references to the literature and specialist sources of information have been included so that those who need to investigate any aspect more deeply will know where to look and inquire.

Any unusual limitations of a material have been emphasized so that it can be checked whether these will be a serious handicap in particular circumstances. Guidance on the testing of materials has also been given so that reliable data can be obtained in environments for which it does not as yet exist. This is particularly important for non-metals, such as rubbers and plastics, for which the effects of changes in formulations on corrosion resistance, etc., are not so well known as for metals.

The precise specification of construction materials is important and attention is drawn to national and international standards where they exist; the use of these usually results in lower costs and quicker deliveries.

Examples of the use of specific materials have been drawn from many industries including those making organic and inorganic chemicals, petrochemicals, fertilizers, pharmaceuticals, fibres, oils and fats. These are all considered as process industries requiring production plant and equipment for the construction of which the materials described here should be considered.

# Introduction to the second edition

All the chapters of the original edition have been revised to include the many developments in metals, plastics, etc., that have occurred in the past seven years. Many changes in national standards and specifications have also been included in the text and tables. The section on brittle fracture has been expanded to cover the considerable progress that has been made in evaluating and selecting materials for low-temperature duties; also a section on fracture mechanics has been added to show how, in the last decade, this technique has been developed into a practical tool for assessing the safety of large vessels and structures.

Information on the costs of materials has again been included to help guide the specifier of engineering materials in the economic consequences of his decisions. Because of the drastic effects of inflation on the prices of all materials these costs are expressed as indices related to basic metals and plastics — carbon steel and polythene — so that the reader may readily convert them to the appropriate values for any time and place.

# Acknowledgements

Extracts have been quoted with permission of the following authorities from whom full copies of their standards may be purchased:

British Standards Institution  
2 Park Street, London W1A 2BS

American Iron & Steel Institute  
1000 16th Street NW, Washington DC 20036

American Society for Testing Materials  
1916 Race Street, Philadelphia, Pennsylvania 19103

Alloy Casting Institute Division, Steel Founders Society of America,  
Cast Metals Federation Building, 20611 Center Ridge Road  
Rocky River, Ohio 44116



# 1

## Carbon and low alloy steels

Carbon steels are alloys of iron, carbon and manganese: most steels have a carbon content of 0.1 to 1% and a manganese content of 0.5 to 2%. Low alloy steels contain, in addition, elements such as nickel, chromium, molybdenum and vanadium in amounts up to 12%. Steels with more than 12% of alloying elements are usually classified as high alloy steels (see Chapter 2).

Sulphur and phosphorus are present as impurities in all iron ores and steel specifications contain maximum permissible values for these in order to limit the number of non-metallic inclusions in the steel. New methods for removing impurities from steels such as electro slag refining and vacuum degassing are now used on a commercial scale to produce steels with impurity levels far below those available a decade ago. These steels are more expensive than those produced from basic oxygen furnaces which have now displaced the open-hearth furnace for the large tonnage production of the general-purpose carbon steels. They are thus only justified for critical applications such as offshore installations and vessels in very corrosive environments.

The pressure-vessel steels have more extensive requirements for certification of composition and mechanical properties and may include requirements for tests at elevated and sub-normal temperatures. Structural steels with guaranteed low-temperature toughness values are also available and are now widely specified for critical structures such as large storage tanks, offshore oil rigs and high-pressure pipe lines for oil and gas.

### Low-carbon steels (mild steel)

In these steels the carbon content is restricted to a maximum of



0.25%; steels with a higher carbon content are difficult to weld. Low-carbon steel is the most commonly used engineering material because it is cheap, has reasonable mechanical properties and is, in most circumstances, a very ductile material. Typical mechanical properties of general-purpose carbon steel plate, e.g. grade 43A in BS 4360 are:

Tensile strength	430	N/mm <sup>2</sup>
Yield strength	230	N/mm <sup>2</sup>
Elongation	20%	
Tensile modulus	210	kN/mm <sup>2</sup>
Hardness	130	DPN
Toughness CVN	30	joules

*Note:* there is an approximate correlation between the hardness and tensile strength of carbon steels of  $\text{DPN} \times (10/3) = \text{tensile strength in newtons per square millimetre}$ .

The tensile or Young's modulus of low-carbon steel at normal atmospheric temperatures is not exceeded by any other steel. Thus, for equipment where rigidity is the limiting factor in design, e.g. storage tanks and distillation columns, high-strength alloy steels have no structural advantage compared with carbon steel. Because of its good ductility, stress concentrations in low-carbon steel structures are relieved by plastic flow and consequently stress analysis of designs in low-carbon steel is not so critical as in high-strength steel and other low-ductile materials.

The fatigue strength of low-carbon steel in air is approximately half the tensile strength. It is reduced by stress raisers such as notches but the effect is not so drastic as with high-tensile steel.

Low-carbon plate and sheet are made in three qualities: fully killed with silicon and aluminium, semi-killed (or balanced) and rimming steel. The extent of the deoxidation or 'killing' of the molten metal determines which type is produced. Fully killed steel is the best quality as most of the impurities are segregated into the top of the billet and can be cropped off leaving clean metal from which plate with very homogeneous properties can be rolled. Fully killed steels are used for pressure vessels requiring very thick plate either because they are large or are operated at very high pressures. Fully killed steel is more expensive than semi-killed steel because of the higher proportion of steel that has to be discarded by cropping. Most general-purpose structural mild steels are semi-killed steels and so are a balance between cost and quality. Semi-killed steels are also used for small pressure vessels. Rimming steels have the minimum amount of deoxidation and are used mainly as thin sheet for consumer applications such as car bodies.

An important development in the production of low-carbon