

# Subsea Pipeline Engineering

2nd Edition



# Contents

<b>List of Figures</b> .....	<b>xiii</b>
<b>List of Tables</b> .....	<b>xix</b>
<b>Acknowledgments</b> .....	<b>xxiii</b>
<b>Preface</b> .....	<b>xxv</b>
<b>1 Introduction</b> .....	<b>1</b>
1.1 Motivation .....	1
1.2 How This Book Is Organized .....	4
1.3 Historical Background .....	6
<b>2 Route Selection</b> .....	<b>11</b>
2.1 Introduction .....	11
2.2 Physical Factors .....	13
2.3 Interactions with Other Users of the Seabed .....	16
2.4 Environmental and Political Factors .....	18
2.5 Case Studies .....	20
<b>3 Carbon-Manganese Steels</b> .....	<b>27</b>
3.1 Introduction .....	27
3.2 Purchasing Pipe .....	28
3.3 Material Properties .....	33
3.4 Pipe Production .....	55

3.5 Pipe Fabrication .....	67
3.6 Pipe Variables .....	76
3.7 Specification Checklist .....	80
<b>4 Increasing Corrosion Resistance .....</b>	<b>83</b>
4.1 Introduction .....	83
4.2 Methods of Improving Corrosion Resistance .....	87
4.3 Available Corrosion-Resistant Alloys .....	97
4.4 Manufacture of Corrosion-Resistant Alloy Pipe .....	106
4.5 Welding of Internally Clad Pipe .....	115
4.6 Evaluating Corrosion Resistance .....	115
4.7 External Protection .....	117
4.8 Cost Comparisons .....	118
<b>5 Welding .....</b>	<b>121</b>
5.1 Introduction .....	121
5.2 Welding Processes .....	122
5.3 Preparation for Welding Operations .....	127
5.4 The Welding Sequence .....	131
5.5 Manual, Semiautomatic, and Automatic Welding .....	135
5.6 Weld Composition .....	136
5.7 Weld-Strengthening Mechanisms .....	137
5.8 Heat-Affected Zone .....	138
5.9 Weld Imperfections .....	140
5.10 Weldability of Pipe Steels .....	145
5.11 Consumable Composition and Coating .....	146
5.12 Welding of Duplex Stainless Steels .....	147
5.13 Welding of Clad Pipe .....	149
5.14 Weld Inspection .....	150
5.15 Preferential Weld Corrosion .....	154
5.16 Downstream Corrosion at Welds .....	155
5.17 Incomplete Penetration .....	155
5.18 Possible Future Welding Techniques .....	156
5.19 Underwater Welding .....	159
5.20 Welding In-Service Pipelines .....	165
5.21 Weld Overlay .....	166

<b>6 Flexible and Composite Pipelines . . . . .</b>	<b>169</b>
6.1 Introduction . . . . .	169
6.2 Fabrication . . . . .	171
6.3 Internal Corrosion . . . . .	181
6.4 Sour Service. . . . .	182
6.5 External Corrosion . . . . .	183
6.6 Failure Modes of Flexible Pipes . . . . .	184
6.7 Inspection of Flexible Pipe. . . . .	185
6.8 Composite Pipelines. . . . .	186
<b>7 Internal Corrosion and Its Prevention . . . . .</b>	<b>189</b>
7.1 Introduction . . . . .	189
7.2 Corrosion Mechanisms . . . . .	192
7.3 Sweet Corrosion . . . . .	196
7.4 Corrosion in Oil Pipelines . . . . .	205
7.5 Effects of Flow on Corrosion in Oil Pipelines. . . . .	207
7.6 Solids in Oil Pipelines . . . . .	211
7.7 Corrosion in Gas Pipelines . . . . .	213
7.8 Effects of Flow in Gas Pipelines . . . . .	217
7.9 Sour Corrosion. . . . .	219
7.10 Water-Injection Pipelines . . . . .	233
7.11 Corrosion Inhibition . . . . .	235
7.12 Microbiological Corrosion . . . . .	238
<b>8 External Corrosion, Coatings, Cathodic Protection, and Concrete . . . . .</b>	<b>247</b>
8.1 External Corrosion . . . . .	247
8.2 External Coatings . . . . .	251
8.3 Cathodic Protection (CP). . . . .	264
8.4 Concrete Weight Coatings. . . . .	293
8.5 Thermal Insulation . . . . .	298
<b>9 Pipeline Hydraulics . . . . .</b>	<b>305</b>
9.1 Introduction . . . . .	305
9.2 Single-Phase Flow of Newtonian Fluids. . . . .	306
9.3 Calculation Example . . . . .	315
9.4 Heat Transfer and Flow Temperature . . . . .	318

9.5 Hydrates .....	320
9.6 Multiphase Flow .....	322
<b>10 Strength.....</b>	<b>327</b>
10.1 Introduction .....	327
10.2 Design to Resist Internal Pressure .....	328
10.3 Design to Resist External Pressure .....	336
10.4 Longitudinal Stress.....	342
10.5 Bending.....	347
10.6 Indentation .....	355
10.7 Impact .....	357
<b>11 Stability.....</b>	<b>361</b>
11.1 Introduction .....	361
11.2 Design Currents .....	362
11.3 Design Waves.....	364
11.4 Hydrodynamic Forces.....	370
11.5 Lateral Resistance.....	380
11.6 Stability Design .....	383
11.7 Interaction with Instability of the Seabed .....	387
<b>12 Marine Pipeline Construction .....</b>	<b>393</b>
12.1 Introduction .....	393
12.2 Lay-Barge Construction.....	394
12.3 Reel Construction.....	407
12.4 Pull and Tow .....	412
12.5 Trenching.....	418
<b>13 Shore Approaches.....</b>	<b>427</b>
13.1 Introduction .....	427
13.2 The Coastal Environment .....	428
13.3 Site Investigation.....	431
13.4 Beach Crossings.....	432
13.5 Horizontal Drilling.....	438
13.6 Rocky Coasts .....	440
13.7 Tunnels.....	441
13.8 Tidal Flats.....	442

<b>14 Upheaval Buckling, Lateral Buckling, and Spans . . . . .</b>	<b>445</b>
14.1 Introduction . . . . .	445
14.2 Upheaval Buckling . . . . .	446
14.3 Driving Force for Upheaval and Lateral Buckling . . . . .	448
14.4 Analysis of Upheaval Movements . . . . .	451
14.5 Measures that Can Be Taken to Prevent Buckling . . . . .	455
14.6 Corrective Action If Buckling Takes Place . . . . .	457
14.7 Lateral Buckling . . . . .	457
14.8 Span Formation . . . . .	460
14.9 Vortex-Induced Vibration . . . . .	461
14.10 Overstress . . . . .	467
14.11 Hooking . . . . .	469
14.12 Span Correction . . . . .	471
<b>15 Internal Inspection and Corrosion Monitoring . . . . .</b>	<b>477</b>
15.1 Introduction . . . . .	477
15.2 Access . . . . .	480
15.3 Inspection Techniques . . . . .	482
15.4 Pigs . . . . .	486
15.5 Corrosion Monitoring: Intrusive Techniques . . . . .	491
15.6 Corrosion Monitoring: Nonintrusive Techniques . . . . .	501
15.7 Fluid Sampling . . . . .	504
<b>16 Risks, Accidents, and Repair . . . . .</b>	<b>507</b>
16.1 Introduction . . . . .	507
16.2 Failure Incidents . . . . .	508
16.3 Reliability Theory . . . . .	516
16.4 Minimizing Risk: Integrity Management . . . . .	521
16.5 Repair . . . . .	522
<b>17 Decommissioning . . . . .</b>	<b>525</b>
17.1 Introduction . . . . .	525
17.2 Legal and Political Background . . . . .	526
17.3 Alternatives . . . . .	527

<b>18 Future Development</b> .....	<b>533</b>
18.1 Introduction .....	533
18.2 Design .....	534
18.3 Materials .....	535
18.4 Connections .....	537
18.5 Construction .....	541
18.6 Maintenance and Repair .....	542
<b>Appendix A: Glossary</b> .....	<b>545</b>
<b>Appendix B: Codes and Standards</b> .....	<b>571</b>
<b>Appendix C: Units</b> .....	<b>583</b>
<b>Index</b> .....	<b>589</b>



# List of Figures

## Chapter 2

- 2-1 Strait of Georgia between the mainland and Vancouver Island . . . . . 21
- 2-2 Strait of Gibraltar . . . . . 23

## Chapter 3

- 3-1 Application of strengthening mechanisms to pipeline steels. . . . . 36
- 3-2 Relation between stress and strain in a tensile test . . . . . 45
- 3-3 Basic oxygen steelmaking and secondary processing. . . . . 56
- 3-4 Continuous casting of steel slab . . . . . 57
- 3-5 Hot-rolling steel plate and strip production processes. . . . . 62
- 3-6 Alternative TMCP processes. . . . . 63
- 3-7 Seamless pipe-manufacturing processes. . . . . 68
- 3-8 Manufacture of ERW and continuous butt-welded pipe . . . . . 70
- 3-9 High-frequency concentration of current density at surface. . . . . 71
- 3-10 U-O-E process. . . . . 74
- 3-11 Manufacture of helical-welded pipe . . . . . 75

## Chapter 4

- 4-1 Effect of chromium and nickel content on the corrosion resistance of steel . . . . . 88
- 4-2 Pitting and crevice corrosion rates as a function of PRE number . . 92
- 4-3 Stress corrosion cracking. . . . . 94



4-4	Comparison of stress corrosion cracking susceptibility of steels . . .	95
4-5	Schaeffler diagram . . . . .	97
4-6	Fabrication of hot-bonded, internally clad seamless pipe . . . . .	108
4-7	Fabrication of hot-bonded, internally clad U-O-E pipe . . . . .	110
4-8	Explosive cladding of steel plate for internally clad U-O-E pipe . . .	111
4-9	Fabrication of internally clad TFP (tight-fit pipe) . . . . .	112

**Chapter 5**

5-1	Submerged arc welding . . . . .	124
5-2	Manual metal arc welding . . . . .	125
5-3	Gas metal arc welding . . . . .	125
5-4	Tungsten inert gas welding . . . . .	126
5-5	Bevels for manual arc welding . . . . .	128
5-6	Bevels for semiautomatic and automatic welding . . . . .	129
5-7	Requirement for preheating for cellulosic electrodes . . . . .	131
5-8	Girth weld fabrication . . . . .	132
5-9	S-lay barge-welding practice . . . . .	132
5-10	The heat-affected zone (HAZ) . . . . .	139
5-11	Underwater welding . . . . .	159
5-12	Girth welding by explosive expansion of a jointing ring . . . . .	165

**Chapter 6**

6-1	Flexible pipelines and risers . . . . .	170
6-2	Fabrication of flexible pipelines and risers . . . . .	171
6-3	Sheath pressure relief systems for flexible pipelines . . . . .	176
6-4	Sacrificial cathodic protection of flexible pipe . . . . .	178

**Chapter 7**

7-1	Generalized view of electrochemical corrosion . . . . .	193
7-2	Sweet corrosion mechanism . . . . .	194
7-3	Corrosion morphologies . . . . .	195
7-4	Sweet corrosion morphology . . . . .	204
7-5	Water entrainment in oil pipelines . . . . .	207
7-6	Sulfide-related cracking morphologies . . . . .	221
7-7	Mechanism of sulfide stress cracking (SSC) . . . . .	224
7-8	NACE MR-0175 domains of SSC . . . . .	226

7-9	ISO 15156 domains of SSC.....	227
7-10	Morphology of hydrogen-induced cracking.....	230
7-11	Conditions in which HIC is important (schematic).....	231
7-12	Corrosion mechanism of sulfate-reducing bacteria.....	240

**Chapter 8**

8-1	Flood coatings.....	253
8-2	Application of extruded coatings.....	255
8-3	Fusion-bonded epoxy (FBE) application.....	256
8-4	Holiday detection: (a) wet sponge, (b) sparking with wire brush, (c) sparking with ring jeeper.....	262
8-5	Concrete impingement.....	294
8-6	Field joint corrosion protection and infill.....	297

**Chapter 9**

9-1	Fluid element in steady horizontal flow.....	306
9-2	Relationship among Reynolds number, friction factor, and roughness.....	309
9-3	Fluid element in steady inclined flow.....	309
9-4	Phase equilibrium of hydrates.....	320
9-5	Flow regime map.....	323

**Chapter 10**

10-1	Forces in a pressurized pipeline.....	329
10-2	Circumferential stress in a pipeline pressurized internally and externally.....	329
10-3	Minimum D/t ratio as a function of $p/2Y$ .....	340
10-4	Histogram of measured collapse pressures.....	341
10-5	Relation between curvature and bending moment.....	347
10-6	Relation between D/t and buckling strain $\kappa R$ .....	349
10-7	Ovalization during bending: (a) forces on elements below and above neutral surface, (b) resultant forces transferred to cross section.....	353
10-8	Indentation of 32-in. pipeline.....	356

**Chapter 11**

- 11-1 Water flow across seabed pipelines: (a) pipeline on bottom,  
(b) pipeline above bottom, (c) pipeline in trench ..... 370
- 11-2 Relation between drag coefficient and Reynolds number  $Re$   
(redrawn from Littlejohns) ..... 372
- 11-3 Relation between lift coefficient and Reynolds number  $Re$   
(redrawn from Littlejohns) ..... 373
- 11-4 Horizontal and vertical reactions between pipeline  
and seabed: (a) monotonically increasing water velocity,  
(b) oscillatory water velocity ..... 381
- 11-5 Onset of seabed instability ..... 388

**Chapter 12**

- 12-1 Lay-barge production. Courtesy of London, C.J. .... 395
- 12-2 S-Lay lay-barge pipelaying schematic (not to scale) ..... 396
- 12-3 Tog Mor lay barge (photograph courtesy of Allseas) ..... 397
- 12-4 Lorelay lay barge (photograph courtesy of Allseas) ..... 400
- 12-5 J-lay lay-barge pipelaying schematic (not to scale) ..... 402
- 12-6 S-7000 lay barge (photograph courtesy of Saipem) ..... 405
- 12-7 Balder lay barge (photograph courtesy of Heerema) ..... 406
- 12-8 Solitaire lay barge (photograph courtesy of Allseas) ..... 406
- 12-9 Chickasaw reel barge (photograph courtesy of  
Global Industries) ..... 409
- 12-10 Hercules reel barge (photograph courtesy of Global  
Industries) ..... 410
- 12-11 Deep Blue reel ship (photograph courtesy of  
Technip-Coflexip) ..... 411

**Chapter 13**

- 13-1 Shore pull ..... 433

**Chapter 14**

- 14-1 Upheaval buckling (schematic) ..... 447
- 14-2 Upheaval buckle of 1,020-mm onshore pipeline in Uzbekistan ... 447
- 14-3 Buckle shown in figure 14-2, profile of pipeline axis and  
ground surface ..... 448

14-4	Design chart .....	452
14-5	Element of pipeline .....	453
14-6	Pipeline laterally moved on sleeper .....	459
14-7	Observed relationship between reduced velocity and oscillation amplitude .....	463
14-8	Span lengths and span assessment .....	466
<b>Chapter 15</b>		
15-1	Corrosion decision tree .....	480
15-2	Pigs .....	487
15-3	Weight loss and electrical-resistance probes .....	492
15-4	Corrosion-monitoring access fitting .....	499
15-5	Installation and retrieval of monitoring devices .....	500
<b>Chapter 16</b>		
16-1	Age dependence of incidence of failure .....	508
<b>Appendix B</b>		
B-1	Test scheme for supplementary requirement U .....	581

# List of Tables

## Chapter 3

3-1	Standard strength grades and yield-to-tensile ratios . . . . .	31
3-2	Typical compositions of pipeline steels . . . . .	32
3-3	Percentage effect of strengthening mechanisms . . . . .	35
3-4	Solid solution strengthening . . . . .	37
3-5	Composition limits before weldability trials required EEMUA Document 166 . . . . .	40
3-6	Effect of alloying elements on steel properties . . . . .	58

## Chapter 4

4-1	Compositions of corrosion-resistant alloys: (a) martensitic stainless steels, (b) austenitic stainless steels, (c) high-molybdenum-chromium-nickel stainless steels, (d) duplex stainless steels, (e) high-nickel alloys . . . . .	86
4-2	Mechanical and corrosion properties of corrosion-resistant alloys. . . . .	90
4-3	Critical crevice corrosion temperatures: Tests in 10% FeCl <sub>3</sub> .6H <sub>2</sub> O at pH 1 for 24-hour exposure . . . . .	93
4-4	Relative costs of solid corrosion-resistant alloys. . . . .	99
4-5	Examples of submarine duplex pipelines . . . . .	102
4-6	Examples of internally clad pipelines and risers . . . . .	107
4-7	Relative cost comparison of pipeline material options. . . . .	118

**Chapter 5**

5-1	Comparison of welding costs . . . . .	136
5-2	Solubility of hydrogen in iron at atmospheric pressure . . . . .	142
5-3	Diffusion coefficients for hydrogen in iron, steel, and stainless steels . . . . .	142
5-4	Diffusivity of hydrogen . . . . .	142

**Chapter 6**

6-1	Properties of thermoplastic liner materials . . . . .	174
6-2	Permeability of liner materials to methane at 50°C . . . . .	175
6-3	Continuous lengths of Coflexip flexible pipe . . . . .	179
6-4	Resistance of thermoplastic materials . . . . .	182

**Chapter 7**

7-1	Comparisons between onshore and offshore pipelines failure statistics . . . . .	190
7-2	Relative occurrence of internal corrosion . . . . .	191
7-3	Corrosiveness of iron sulfides . . . . .	222
7-4	Stress corrosion cracking environments . . . . .	224
7-5	Prandtl numbers for calculation of corrosion rates in seawater injection pipelines . . . . .	235
7-6	Growth limitations for sulfate-reducing bacteria . . . . .	238

**Chapter 8**

8-1	Potential corrosion rates of steel in seawater . . . . .	248
8-2	Reference electrode potentials . . . . .	267
8-3	Evaluation of microbial activity of sediments . . . . .	269
8-4	Protection potentials ranges for steel . . . . .	270
8-5	Under- and overprotection potentials for steel pipelines . . . . .	272
8-6	Sacrificial anode materials . . . . .	273
8-7	CP current requirements, according to NACE RP-0176 . . . . .	273
8-8	CP current requirements, according to DNV RP-B401 . . . . .	274
8-9	CP current requirements, according to DNV RP-F103 . . . . .	274
8-10	Coating breakdown values, according to DNV RP-F103 . . . . .	276
8-11	Field joint coating breakdown values, according to DNV RP-F103 . . . . .	276
8-12	Resistivity design values for anodes . . . . .	282

**Chapter 15**

15-1	Inspection and monitoring techniques .....	481
15-2	Operating parameters linked to corrosion .....	504

**Appendix B**

B-1	Limit states, safety classes, and failure probabilities. ....	579
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# Preface

Submarine pipelines are the arteries of the oil and gas industry, important in engineering practice and full of excitement and interest, though at first sight less spectacular than platforms and floating production systems. The technology has advanced dramatically. Projects that were dreams 20 years ago are now becoming reality.

I came into this field by lucky chance. I was a university lecturer in Cambridge, and in the summer of 1970, I was invited to spend the summer at Brown University, where I had completed my PhD five years earlier. The Alaska pipeline was in the news. Former colleagues in the Division of Engineering remembered that I had worked on permafrost as a sideline to my PhD, and they had some money for research on geotechnical aspects of environmental problems. They told me that if I could oversee the research, they could support me for the summer. I was keen to go and networked through a colleague in Cambridge to locate the people in British Petroleum (BP) in London who were working on the problem. I told them that I was not looking for money but was looking for an interesting problem. Impressed by this refreshingly naive approach, they gave me a problem to do with differential settlement on thawing permafrost; I researched that topic and was taken to talk to the pipeline team in Houston.

A year later, BP called me again and said that there were questions about a planned North Sea pipeline, Forties, the first large-diameter line in what was then thought of as deep water, 125-m deep.

“That sounds interesting,” I said, “but I don’t know anything about underwater pipelines.”



“We think that’s an advantage,” they replied. “You’ll bring a fresh mind to it. Come and see us tomorrow.”

That phone call changed my life. Over the next few years, I worked on a number of problems, among them pipelaying mechanics, buckle propagation, interaction with sandwaves, modeling, and surface tie-in. Since then, most of my work has been in pipelines. In 1975 I went to work for the leading consultant in underwater pipelines, R.J. Brown and Associates, and worked on projects in Arctic Canada, the North Sea, and the Middle East. It was in that period that I first met my friend and co-author Roger King, and later we worked together at University of Manchester Institute of Science and Technology (UMIST). Ten years later, I started my own consulting company, Andrew Palmer and Associates, and we worked on exciting projects in every continent.

There are many books, and each one needs a reason for its existence. Our justification for the present book is that we believe—and, more importantly, others have confirmed to us—that there is no other book that covers the same ground, though there are excellent books on land pipelines and on outfalls. There are many technical papers, but most of them are in the conference literature and are not readily accessible. Roger and I thought it useful to bring together in one volume the state of the art in a form that would be accessible to the nonspecialist and at the same time would provide references to topics that we did not have space to follow up in detail. We are primarily concerned with oil and gas pipelines that operate at relatively high pressures and sometimes in very deep water, but most of the ideas are equally applicable to lines that carry water and sewage.

No doubt there are mistakes. They are our responsibility, and we hope that readers will tell us about them.

The authors have taken this opportunity to remove outdated material, correct mistakes, and reflect new developments. They welcome comments and suggestions.

Singapore and Manchester  
July 26, 2007

# 1

# Introduction

## 1.1 Motivation

Humankind needs to move fluids from place to place. Some fluids have to be moved in huge quantities and over long distances: water, oil, natural gas, and carbon dioxide are examples. Other fluids have to be moved in smaller quantities or over shorter distances: steam, ethylene, blood, milk, wine, helium, mercury, nitroglycerin, and petrochemicals are examples.

There are essentially three ways of moving fluids. The first is to pour the fluid into a tank, move the filled tank to where the fluid is needed, and empty the tank. The basic components of that method are a tank that can be moved and a way of filling and emptying it. The second way is to construct a pipe from where the fluid is to where the fluid needs to be, then pump the fluid along the pipe. The third way, sometimes used in combination with the other two, is to transform the fluid into a solid or another fluid that can be transported more easily.

## 2.5 Case Studies

Two case studies exemplify the interaction among different factors. British Columbia Hydro and Power Authority (BC Hydro) wished to build a pipeline across the Strait of Georgia, from the Fraser Delta area south of Vancouver to a landing on Vancouver Island. The project is described in greater detail by Park.<sup>10</sup> The plan was to construct two lines to obtain additional security, and to make the diameters 273.05 mm OD (outside diameter; nominal 10-inch), chosen to match the expected demand. Figure 2–1 is a sketch map.

The political boundary between Canada and the United States at 49° N lies just south of the delta, cuts across the Point Roberts peninsula, and extends westward to the middle of the Strait of Georgia. BC Hydro decided early on not to cross that boundary, because to do so would have brought part of the pipeline under the jurisdiction of U.S. federal authorities, as well as numerous state and local authorities, and would make it liable to a challenge in the U.S. legal system.

The land portion of the delta consists of low-lying islands. The delta is fronted by a tidal flat, Roberts Bank, which is mostly dry at low tide and covered by about 1 m of water at high tide. The landward sections of the bank are covered by grasses and seaweeds, and are fish spawning areas, so it was decided to schedule construction to avoid the spawning season. The top of the bank is almost level, but the foreslope on the seaward side is relatively steep.

British Columbia has fewer earthquakes than California to the south or Alaska to the north, but there are occasional large earthquakes. Oscillatory shear stresses induced by an earthquake might liquefy the loose and geologically recent sand and silt sediments of the bank, and parts of the foreslope could then become unstable, liquefy, and slide downhill into deeper water. The risk of liquefaction is least where the gradient of the foreslope is smallest, about mid-way between the South Arm of the Fraser and Canoe Pass, and so it was decided that the pipeline should traverse the foreslope at that point. The route runs straight down the slope, so that if a flowside should occur, the sand would flow along the pipeline rather than across it. The reason for that choice of direction is that a pipeline can withstand very large forces applied along its length but only smaller forces applied across its length.

A plot of toughness against temperature appears as two plateaus linked by a sloping ramp. The toughness of steel, measured as its resistance to sudden impact, is only slightly reduced with reducing temperature from ambient until the upper critical temperature is reached. At and below this temperature, the toughness of the steel declines. Below the lower critical temperature, the impact resistance of the steel remains relatively constant at the lower value. The nonductile transition temperature is the temperature roughly halfway between the two critical temperatures. For high-carbon steels, the transition ramp between the upper and lower shelves is steep, and for low-carbon steels, the ramp is gradual. The plateaus are called the upper and lower *shelves*. The broken surfaces are usually examined after the impact testing. Ductile failures show a rough cup-and-cone appearance, and the ratio of this area to the complete fracture surface is used as a parameter in evaluating the point of changeover from ductile to brittle behavior. For pipeline materials, a typical requirement is 85% ductile fracture at the given test temperature.

The point of transition from ductile to brittle is defined as the nonductile transition temperature (NDTT). This is the temperature at which the fracture surface appears 50% ductile and 50% brittle. One major unresolved problem is that the different test methods and their interpretations give different critical temperatures. It is important that the test method to be used and the test result interpretation are agreed upon by the specifier and material provider.

The NDTT is a function of metal composition and grain size, item thickness, and rate of impact. The slope of the ramp reflects the statistical variation of these properties within the steel. Thick section material has a higher transition temperature than thin metal because the thin material can yield, thus reducing the effective rate of transfer of stress. Slow impact loading allows the material to deform in a plastic manner, reducing the NDTT. Pipeline testing generally uses full thickness specimens of pipe, though thinner samples can be used if the pipe wall thickness is very large, but this variation in testing is subject to negotiation between the purchaser and the pipe producer.

Whereas strength of materials is well understood, toughness is not. Toughness is increased by reducing alloying content and/or decreasing the grain size. However, other factors are important, for example, the degree of segregation of phases within

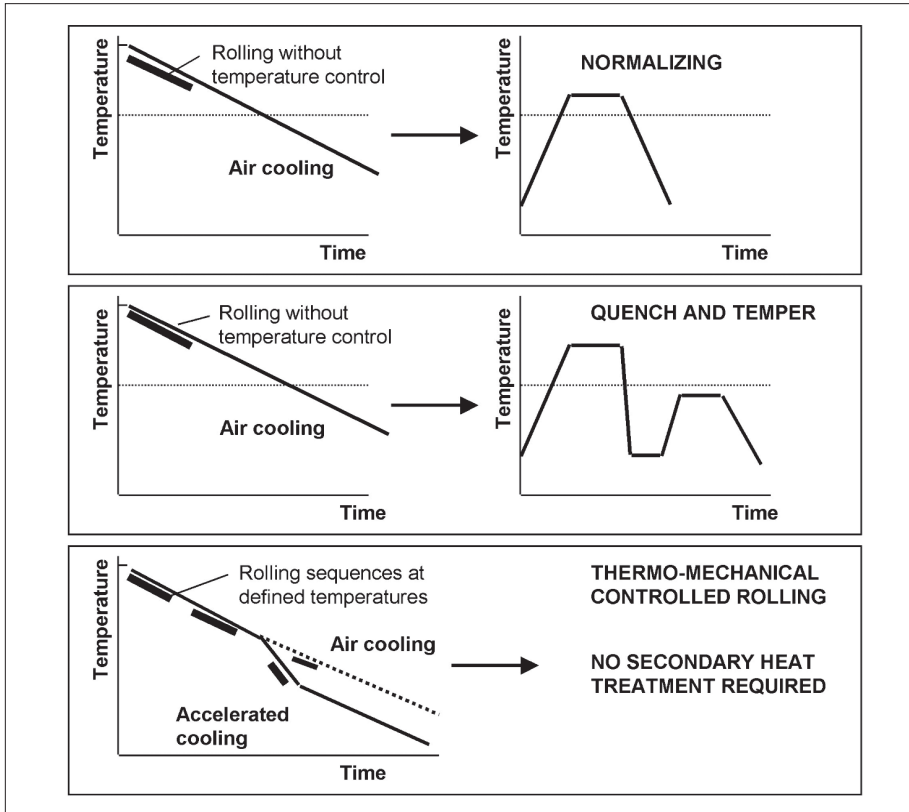


Fig. 3-5. Hot-rolling steel plate and strip production processes

Option 1 of figure 3-6 is the simplest TMCP and is the original controlled-rolling process developed to produce large sheets of high-strength steel for construction of ships and super tankers. The slab is heated to 1,200–1,250°C, and the steel is rolled to the *roughing* stage. The plate is allowed to cool to a temperature where it remains austenitic, but reworking the grains will not recrystallize as a result of the work input during the second phase of rolling. The steel is cooled further until it is on the borderline of the transition zone of austenite to ferrite, and is finished by rerolling at this temperature to form elongated, austenite grains. On further cooling, the steel recrystallizes into fine ferrite and pearlite grains. The energy input in working of the austenite grains at the transition temperature results

## 4.3 Available Corrosion-Resistant Alloys

### 4.3.1 Metallurgical structure

The structure of a stainless steel can be determined from the Schaeffler diagram (fig. 4-5). Some alloying elements promote the formation of ferrite (e.g., chromium), while others promote the formation of austenite (e.g., nickel). The diagram in figure 4-5 maps the complete range of stainless steels. The formulas used to determine where an alloy is located on the Schaeffler diagram are listed here:

Chromium equivalent (ferrite forming) =

$$\text{Cr} + 2 \text{Si} + 1.5 \text{Mo} + 5 \text{V} + 5.5 \text{Al} + 1.75 \text{Nb} + 1.5 \text{Ti} + 0.75 \text{W} \quad (4.6)$$

Nickel equivalent (austenizing) =

$$\text{Ni} + \text{Co} + 0.5 \text{Mn} + 0.3 \text{Cu} + 25 \text{N} + 30 \text{C} \quad (4.7)$$

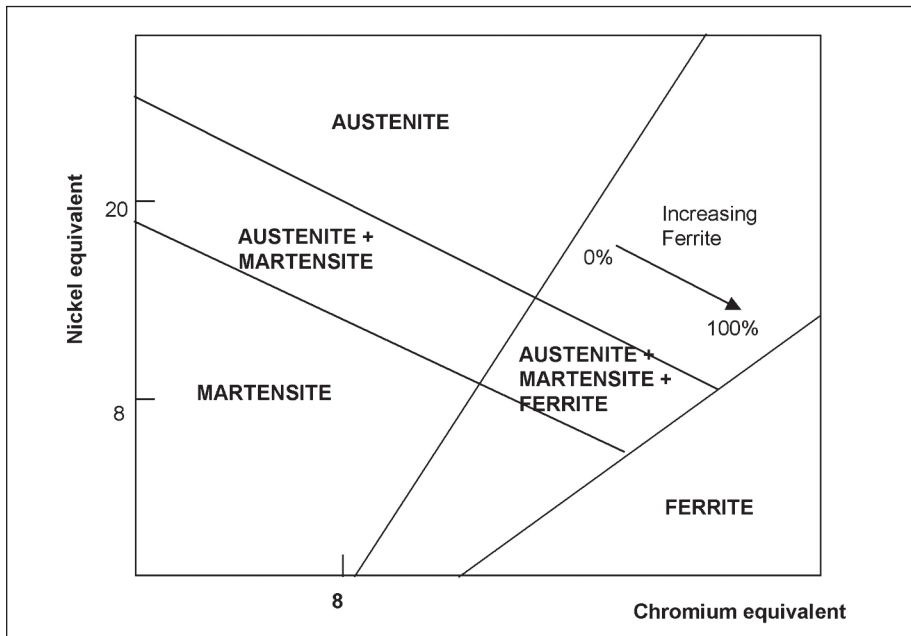


Fig. 4-5. Schaeffler diagram