# APPLIED WELDING ENGINEERING PROCESSES, CODES AND STANDARDS RAMESH SINGH

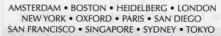
B H

# Applied Welding Engineering: Processes, Codes and Standards

By Ramesh Singh

British Elbrury Critifoguiogelti-Priblicat









## Contents

Ackr	nowledgment		XX
	Cast Iron		
18	None of Cart Iron among GA		
	ction 1		
Int	roduction to Basic Metallurgy		
1.	Introduction		
**			
	Pure Metals and Alloys		
	Smelting		
	Iron		
	Sponge Iron		
2.	Alloys	Herining Reactions	
	Alloys		
	Effects of Alloying Elements		
	Carbon Steels		
	Sulfur		
	Manganese		
	Phosphorus		
	Silicon		
	Alloy Steels		
	The Effect of Alloying Elements on Ferrite	Semi-Killied Steel	
	Effects of Alloying Elements on Carbide		-
	Philipp		
3.	Physical Metallurgy		1
	Crystal Lattices		1
	Crystal Structure Nomenclature		1
	Solidification		1
	Lever Rule of Solidification		1
	Constitutional Supercooling		1
	Elementary Theory of Nucleation		1
	Allotropy		1
	Crystal Imperfections		2
	Grain Size		2

4.	Structure of Materials		23
	Phase Diagrams Different Types of Phase Diagrams Iron-Iron Carbide Phase Diagram		24 24 28
	Explanation of the Iron-Carbon Phase		28
	Rationale for Letter Designations in the	e Iron-Iron Carbide Phase	
	Diagram		32
5.	Production of Steel		33
	The Electric Arc Furnace (EAF) Process		22
	Furnace Charging	Figorit	33 34
	Melting		35
	Refining		36
	Phosphorus Removal		36
	Sulfur Removal		37
	Nitrogen and Hydrogen Control		37
	De-Slagging		38
	Tapping		38
	Basic Oxygen Furnace (BOF)		39
	Refining Reactions		40
	Carbon		40
	Silicon		40
	Manganese		41
	Phosphorus		42
	Sulfur Removal		43
	Deoxidation of Steel		44
	Rimmed Steel		45
	Capped Steel		46
	Semi-Killed Steel		46
	Killed Steel		46
	Deoxidation Equilibria		47
	The Iron-Iron Carbide Phase Diagram		50
6.	Classification of Steels		51
	Carbon Steels		53
	Low-Carbon		53
	Medium-Carbon		53
	High-Carbon		54
	Ultrahigh-Carbon		54
	High-Strength Low-Alloy (HSLA) Steels		54
	Classification of HSLA		54

Contents

Low-Alloy Steels	
Low-Carbon Quenched and Tempered Steels	
Medium-Carbon Ultrahigh-Strength Steels	
Bearing Steels	
Chromium-Molybdenum Heat-Resistant Steels	to gradulated leading
AISI Series	
Some Example AISI Classifications	
Cast Iron	
Types of Cast Iron	
White Cast Iron	
Malleable Cast Iron	
Management of the state of the	
Ferritic Malleable Iron	
Plack Heart Cart has	
Donulita Mallaghia Castila	
Pearlite Malleable Cast Iron	
Martensitic Malleable Iron	
Gray Cast Iron	
Lastability of Gray Cast fron	
Chilled Cast Iron	
Nodular (Spheroidal Graphite) Cast Iron	
Castability, Solidification and Shrinkage	
Alloy Cast Irons	
Stainless Ctaala	
Stainless Steels	
Stainless Steel Production	
Forming	
Heat Treatment	
Cutting Stainless Steel	
abrication of Stainless Steel	
Velding and Joining	
vnes of Stainless Steels	
Classification of Stainless Steel	
Martensitic Stainless Steels	Fracture
Martensitic Stainless Steels Ferritic Stainless Steels	
Martensitic Stainless Steels Ferritic Stainless Steels Pitting Resistance Equivalent (PRE)	
Martensitic Stainless Steels Ferritic Stainless Steels	Fracture Fracture Control

9.	Non-Ferrous Materials	Low-Alloy Steels
	Copper and Copper Alloys	
	Aluminum and Aluminum Alloys	
	Physical Metallurgy of Aluminum	
	Effect of Alloying Elements on Alui	
	Effect of Iron	AlSi Series Land and real real real
	Effect of Silicon	
	Effect of Manganese	
	Effect of Magnesium	
	Effect of Copper	
	Effect of Zinc	
	Effect of Chromium	
	Effect of Zirconium	
	Effect of Lithium	
	Age Hardenable Alloys	
	Nickel and Nickel Alloys	
	Titanium and Titanium Alloys	
10.	Working With Metals	Canadidity of Case Case Iron
	Elastic Limit	
	Plastic Deformation	
	Polycrystalline Materials	
	Cold Working	
	Stored Energy	
	Restoring the Lattice Structure of A	
	Work – Annealing	Stainlest Sued Freduction
	Grain Growth	
	Hot Working	
	THOU WORKING	
11.	Mechanical Properties and T	esting of Metals 8
	Strength of Materials	Televication of Statistics Steel, ma
	Elastic and Plastic Behavior	
	Ductile vs. Brittle Behavior	
	Failure	Classification of Stainless Steel
		Attorneous Staintest Steels
	Fracture Control	Territor Stateliese Steple
	Fracture Control	Printed Resistance Foundation (PKE
	Crack Growth and Fracture	According Straingles Appell
	Damage Tolerance	Combine Spanning Street
	Failure Analysis	Province Manufacture (PFI) Star
	lesting of Metals	
	Tensile Test	

Contents	xi

	Hardness Test	93
	Impact Test	94
	Creep Test	
	Fatigue Test	
	and a state of the	
12.		
	TTT and CCT Curves	96
	Isothermal-Transformation (IT) or (TTT) Diagrams	96
	Cooling Curves	98
	Cooling-Transformation (C-T) Diagrams	98
	Stress Relief Annealing	98
	Normalizing	100
	Annealing	100
	Spheroidizing	101
	Tempering	102
	Austempering of Steels	102
	Martempering	102
	Hardening	103
	Hardening by Martensite Transformation	103
	Case Hardening and Carburizing	103
	Process of Quenching	105
	Heat Treatment of Non-Ferrous Material	105
	Heat Treatment of Copper and Copper Alloys	105
	Heat Treating Aluminum and its Alloys	106
	Heat-Treating Furnaces	106
	Liquid Heating Baths	107
	Elquid Treating Datis	107 107
Se	ction 2	
	elding Metallurgy and Welding Processes	
1.	Introduction	111
	Welding Procedures	112
	Liberty Discreption   Invalvot galaxies and inter-	
2.	Physics of Welding	115
	Heat	116
	Details of the Heat-Flow in Welding	
	Heat in Arc Welding Processes	
	Heat in Plasma Arc Cutting and Welding	
		121
	Tieut in Resistance Welding	122
	Heat in Welding Processes using Chemical Sources	
	Thermit Welding	125

Friction Welding	12
The state of the s	
Ultrasonic Welding	tell que 12
Explosion Welding	12
Heat by Focused Sources	12
Laser Beam Welding (LBW)	12
Flectron Ream Welding (FRW)	13
Other Sources of Heat in Welding	13
Application of the Principles of Welding Physics	13
Pre-Heating	13
Determining the Need for Pre-Heat and the Temper	ature 13
Post-Weld Heat Treatment (PWHT)	13
Heat and Time in Welding	13
Heat Input	14
Energy Distribution	14
Rate of Heating	14
Maximum Temperature	14
Heat Generation and Temperature Distribution - I	Practical
Application	14
Time at Temperature	14
Cooling Rates	14
Base Metal Mass	14
3. Welding and Joining Processes	14
Shielded Metal Arc Welding (SMAW): Process Fund	damentals 15
How the Process Works	A potroit blood 15
Covered Electrodes Used in the SMAW Process	15
Joint Design and Preparation	15
Gas Tungsten Arc Welding (GTAW): Process Descri	iption 15
Process Advantages and Limitations	15
Electrodes	mortal bound 15
Joint Design	15
Gas Metal Arc Welding (GMAW)	15
Process Description	15
	15
Joint Design	15
	at set to stage 15
	May 15
at a la li di decidi	A
	16
-1	16
C 1	16
Process Description	16

Contents xiii

Materials	
Other Common Joining and Welding Pro	ocesses
Electroslag Welding (ESW)	
Plasma Arc Welding (PAW)	
Stud Welding	
Oxy-fuel Gas Welding (OFW)	
Brazing and Soldering	
Arc-Welding Power Sources	
Constant Voltage Power Source	
Constant-Current Power Source	
Transformers	
Thyristor-Silicon Controlled Rectifiers (SCF	(2)
Generators	Variation Statistics State
Alternators	
Physical Effect of Heat on Materia	al During Welding
The Molten Metal	
The Welded Plate	
Influence of Cooling Rate	
Stresses, Shrinkage and Distortion Stresses in Weldments	ii iii vveidilielits
Definitions of Terms	
Development of Stresses	
Moving Localized Heat Source	
Distribution of Stress in a Simple Weld Residual Stresses	
Shrinkages	
Shrinkages Shrinkage Transverse to a Butt Weld	
Shrinkage Longitudinal to a Butt Weld	
Distortion in Weldments	
General Description	
Angular Distortion	
Buckling	
Corrective Measures	
Thermal Straightening	
Designing Weld Joints	
Assessing the Strength of Welds	
Throat of a Wold	
Throat of a Weld Sizing a Fillet Weld	

	Weld Size and Cost Control	188
	Control of Welding Stresses to Minimize Through-Thickness Failure	5 103
6.	Welding Corrosion Resistant Alloys – Stainless Steel	191
	Corrosion Resistant Alloys (CRAs)	192
	Stainless Steel	192
	Welding Stainless Steel	192
	General Welding Characteristics	192
	Welding Processes	194
	Protection against Oxidation	194
	Welding Hygiene	194
	Austenitic Stainless Steels	195
	Metallurgical Concerns Associated with Welding Austenitic	
	Stainless Steels	195
	Mechanical Properties of Stainless Steels	196
	Welding of Austenitic Stainless Steels	196
	Superaustenitic Stainless Steels	198
	Material Properties and Applications	198
	Welding and Joining of Superaustenitic Stainless Steels	198
	Difficulties Associated with Welding Stainless Steel	199
	Martensitic Stainless Steels	202
	Properties and Application	202
	Welding Martensitic Stainless Steels	203
	Ferritic Stainless Steels	205
	Properties and Application	205
	Welding Ferritic Steel	206
	Precipitation Hardened Stainless Steels	206
	Properties and Application of Precipitation Hardened Steels	206
	Welding Precipitation Hardened (PH) Steels	207
	Duplex Stainless Steels	210
	Mechanical Properties	210
	Heat Treatment	212
	Welding and Fabrication	212
7.	Welding Non-Ferrous Metals and Alloys	215
	Aluminum and its Alloys	216
	The Confusing Thing about Aluminum	216
	Weld Hygiene	217
	Pre-Heating	217
	The Conductivity of Heat	217
	Welding Filler Metals	218
	Welding Aluminum with the Shield Metal Arc Welding (SMAW)	
	Process	218

8.

Welding Aluminum with the Gas Tur	ngsten Arc Welding (GTAW)
Process	maint bland and get 22
Type of Current and Electrode	mylesti bahlaw lauseill 22
Grinding the Tip of the Electrodes	al mery student of exempt 22
Welding Aluminum with the Gas Me	etal Arc Welding (GMAW)
Process	22
Power Source	22
Wire Feeder	22
Welding Guns	222
Welding Technique	nolloubertal 22
The Push Technique	222
Travel Speed	ght (TV) noibhigent fauei 7 222
Shielding Gas	contrasqual leastly to assestments. 22
Welding Wire	223
Friction Stir Welding (FSW)	223
Nickel Alloys	224
Heat Treatment	nottelball to come 224
Mechanical Properties	224
Fabrication	AM bus vX to lost 225
Precipitation-Hardenable Nickel-Base	
Heat Treatment of PH Nickel Alloys	Imamellipä yaki X 225
Mechanical Properties	225
Welding	lemel lement 226
Titanium Alloys	220
Heat Treatment	esmuod sidnina. 222
Alpha (α) Titanium	±1.1-1.11 222
Alpha/beta (α-β) Titanium	227
Beta (β) Titanium	planten communication design graduati 227
Wald Dafa da and Income diam	Single Wall Single Indig 19Win
Weld Defects and Inspection	229
Weld Quality	WCI resemble in the Manuary 229
Acceptance Standards	An egent sides I find sides 229
Discontinuities in Fusion Welded Join	nts 230
Classification of Weld Joint Discontin	nuities 23°
Typical Weld Defects	232
Porosity	233 Paris 233
Inclusions	nothing and places less 234
Incomplete Fusion	234
Inadequate Joint Penetration	234
	ullOff refailed with O guml 234
Underfill	235
Overlap	235
Cracks	gnilasi alabhay attangaM 235
Surface Irregularities	ability of an angular transfer of 236

	Base Metal Discontinuities		236
	Designing Weld Joints		236
	Basis of Welded Design		237
	Stresses in Pressure Vessels		241
	Pipelines		242
Se	ection 3		
No	on-Destructive Testing		
1.	Introduction		247
_			
2.	Visual Inspection (VT)		249
	Advantages of Visual Inspection		250
	Skalintesa Phalla		250
3.	Radiography		253
	All Mallins are discounted from the facility		
	Source of Radiation		
	X-Rays Effect of Kv and MA		255
	Scatter Radiation		257
			258
	X-Ray Equipment Power Sources		259
			259
	Gamma Rays Artificial Sources		
	Half-Life		
	Film		
	Radiographic Exposure Techniques		263
	Single Wall Single Image (SWSI)		-
	Panoramic Technique		266
	Double Wall Single Image (DWSI)		266
	Double Wall Double Image (DWDI)		
	Radiographic Image Quality		266
	Radiographic Contrast	Discontinuitles in Fusion Walds	268
	Subject Contrast		268
	Film Contrast		269 269
	Radiographic Definition		270
	Exposure Geometry		270
	Film Graininess		271
	Image Quality Indicator (IQI) or Pene	etrameter	272
	Radiation Safety	USIA NO.	272
	Minister February Scholar		2/2
4.	Magnetic Particle Testing		275
	Principles of Magnetic Particle Testing	Sydate Imguladites	276
	Calculating Magnetizing Current		277

Contents	xvii
	AVII

	Types of Magnetizing Current		278
	, and the same of		279
	0		279
	Drying after Preparation		279
	The second of th		279
	Alternating Current		279
	Direct Current		280
	Continuous or Residual Application of Current		280
	Dry Method of Inspection		281
	Wet Method of Inspection		281
	Viewing Conditions		282
	Inspection under Ultraviolet (Black) Light		282
5.	Penetrant Testing		283
	General Procedure		284
	Penetrant Materials		284
	Specific Requirements		284
	Control of Contaminants		284
	Surface Preparation		285
	Drying after Preparation		286
	Techniques		286
	Techniques for Standard Temperatures		286
	Penetrant Application		286
	Penetration Time (Dwell Time)		287
	Excess Penetrant Removal		287
	Removing Excess Water-Washable Penetrant		
			287
	Removing Excess Post-Emulsifying Penetrant		287
	Removing Excess Solvent-Removable Penetrant		287
	Drying Process after Excess Penetrant Removal		287
	Developing Interpretation		288
	Final Interpretation		288
	·		288
	Characterizing Indication(s) Color Contrast Penetrant		288
			289
	Fluorescent Penetrant Evaluation		289
			290
	Liquid Penetrant Comparator	11000.000000000	290
5.	Ultrasonic Testing		293
	Theory of Sound Wave and Propagation		294
	Theory of Sound		295
	Piezoelectricity		296
	Sound Beam Reflection		296
	Sound Beam Frequencies		296

	Sound Beam Velocities		297
	Snell's Law of Reflection and Refraction		298
	Understanding the Variables Associated with U	Iltrasonic	
	Testing		299
	A-Scan Equipment		
	B-Scan Equipment		
	Role of Coupling in Testing		
	FILE CONTRACTOR		
7.	Eddy Current Testing		305
	Method		305
8.	Acoustic Emission Testing (AET)		307
	Ongoing Developments in the AET Field		307
	Future of AET		200
9.	Ferrite Testing		201
	Effect of Ferrite in Austenitic Welds		
	Effect of Ferrite in Austenitic Welds		321
10.	Pressure Testing		323
10.	Attitude School		
	Method		
	Proof Testing		100000
	Practical Application of Hydrostatic Testing Critical Flaw Size		
	Critical Flaw Size		1.5012.00
_	And agraphic image Quality		
the Street of the Street	.11011 4		
Coo	des and Standards		
1.	Introduction		331
2.	Codes, Specifications and Standards		333
	American Society of Mechanical Engineers (ASME)		334
	Background and History		334
	Present Day ASME		336

Contents

List of all Twelve ASME Boiler and Pressure Vessels Codes	336
ASME Section VIII, Division 1 (Pressure Vessels)	337
ASME Code for Pressure Piping	337
ASME Section V	340
The National Board	340
The National Board Inspection Code (NBIC)	342
American Petroleum Institute	342
API 653 (Above-Ground Storage Tanks)	343
API 510 (Pressure Vessels)	343
API 570 (Pressure Piping)	343
API RP 579 (Fitness for Service)	343
API RP 580 (Risk Based Inspection)	343
American Society for Testing Materials (ASTM)	343

Index 347

### Index

A	C (16 a Call) definitions having property
Acicular ferrite, 20, 54	Capped steel, 46
Acicular ferrite steel, 54	Carbon Equivalent (CE), 58
Acoustic, 293	Carbon steel, 9, 38, 53, 72, 152, 162, 192,
Acoustic emission testing (AET), 307	194, 197, 199
AISI Series, 56	Carbon steels, 53
Allotropy, 18	Case hardening, 103
Alloy, 7	Cast irons, 5, 57
Alloy cast iron, 64	Cementite, 9, 30, 61
Alloy steels, 9	Chilled cast iron, 59, 63
Alpha (a) brass, 75	Chromium-molybdenum heat-resistant
American Petroleum Institute, 342	steels, 55
American Society for Testing	Circular magnetizing, 277
Materials, 343	Close-packed hexagonal, 14
American Society of Mechanical	Cold working, 85
Engineers, 334	Color contrast peneterant, 289
Annealing, 66, 85, 100, 206, 227	Conduction, 17, 35, 112, 140, 150, 170, 217
API 510, 343	Constitutional supercooling, 16
API 570, 343	Control-rolled steels, 54
API 653, 343	Convection, 17, 35, 112, 150
API RP 579, 343	Crack size, 90, 187
API RP 580, 343	Crack tip opening, 326
A-scan, 301	Crack tip opening displacement, 188
ASME Code for pressure piping, 337	Creep, 21, 89, 208, 326
ASME Section V, 340	Creep, 94
ASME Section VIII, Division, 1, 337	Critical surface flaw sizes, 327
Austempring, 102	Crystal, 13
Austenite, 10, 11, 18, 19, 28, 30, 54, 61,	Crystal structures, 13, 14
172, 174, 199, 201, 202, 205, 210,	Crystals, 21, 296
212, 214, 321	C-scan, 301
Autogenous, 155	C-T diagram, 98
B (001 grain discorp	D 991 28 amoth
Basic Oxygen Furnace (BOF), 33, 39	Damage tolerance, 91
Bearing steels, 55	Dendrites, 16, 17
Binary diagram, 25	Deoxidation equilibrium, 47
Binary phase, 27	De-slagging, 38
Bivariant equilibrium, 25	Developer, 288
Black heart cast iron, 60	Diffusion welding (DFW), 131
Black light, 276, 290	Dislocations, 21
Body-centered cubic (bcc), 14	Duplex stainless steel, 73
Brazing, 165	Daplex statilless steel, 15
Brinell, 93	E E
Brittle fracture, 89, 94	Eddy current testing, 305

B-scan, 301

Elastic and plastic deformation, 88

Elastic limit, 83
Electric Arc Furnace, 33
Electro magnetic, 276
Electron acceleration, 255
Electron beam welding (EBW), 128
Electroslag welding (ESW), 122, 161
Energy input, 117
Engineering critical evaluation (ECA), 188
Equilibrium, 14, 16, 18, 23, 100, 178
Eutectic, 8, 27, 28, 30, 58, 62
Explosion welding (EXW), 128
Exposure arrangements, 265

### F

Failure, 89
Failure analysis, 91
Fatigue, 10, 64
Fatigue fracture, 89
Ferrite, 9, 11, 18, 19, 28, 30, 31, 54, 60, 172, 197, 199, 201, 202, 205, 210, 212, 321, 322
Film, 263
Film contras, 269
First Critical Angle, 298
Fluorescent peneterant process, 289
Flux core arc welding (FCAW), 158
Fracture, 84, 89, 91, 187
Fracture control, 90

Face-centered cubic (fcc), 14

### G

Gas metal arc welding (GMAW), 157 Gas tungsten arc welding (GTAW), 155 Grain boundaries, 21, 93 Gray cast iron, 58

Friction welding (FRW), 126

### H

Hadfield manganese steel., 10 Hardness, 85, 102 Heat in arc welding processes, 120 Heat treatment, 55, 70, 95, 208, 227 High-carbon steels, 54 High-strength low-alloy (HSLA), 54 Hydrostatic test, 324

### I

Image quality indicator (IQI), 272 Impact test, 94 Interpretation, 288 Invariant equilibrium, 25 Inverse square law, 256 Iron, 4 Isothermal (IT) diagram, 96

### K

Killed steel, 46 Kish-graphite, 58 Knoop, 93

### L

Laser beam (LBW), 128
Leak test, 323
Lever rule of solidification, 14
Liquid peneterant comparator, 290
Liquid peneterant testing (PT), 283
Liquidus, 16
Longitudinal magnetizing, 277
Longitudinal waves, 295
Low-alloy steels, 55
Low-carbon steel, 53

### M

Magnetic particle testing, 275
Malleable cast iron., 58
Manganese, 8
Martempering, 102
Martensitic malleable iron, 60
Maximum operating pressure (MOP), 325
Mechanical metallurgy, 3
Medium carbon steels, 53
Metastable, 17, 20, 23, 30
Microalloyed steels, 54
Microhardness, 93

### N

Nickel and nickel alloys, 81 Nickel steels, 10 Nitriding, 104 Non-destructive testing (NDT), 247 Nonaqueous developer, 288 Normalizing, 100 Nucleation, 17

### 0

Oxy-fuel welding (OFW), 124, 164

### P

Pearlite, 10, 30, 54, 172, 174, 201 Pearlite malleable iron, 60 Pearlite-reduced steels, 54 Penumbral shadow, 271 Peritectic, 28, 30 Phase diagram, 15

Phase diagram of iron-iron carbide, 28 Phosphorous, 9 Phosphorus reversion, 38 Physical metallurgy, 3 Piezoelectricity, 296 Pitting resistance, 71 Plasma arc, 121 Plasma arc welding (PAW), 162 Plastic deformation, 84 Pneumatic test, 324 Polycrystalline, 84 Post weld heat treatment (PWHT), 196 Power sources, 166 Precipitation hardening, 206 Preheating, 133 Process metallurgy, 3 Proof test, 324

### Q

Quality, 229 Quenching, 105

### R

Radiation, 17, 35, 112, 129, 150, 253, 254, 255, 256, 258, 261, 262, 266, 268, 269, 272, 274

Radiation exposure, 269, 273
Radioactive isotopes—gamma ray, 254
Radiographic contrast, 268
Radiographic definition, 268
Radiographic film, 263
Radiographic image quality, 268
Rayleigh waves, 295
Refining, 3, 36, 38, 204
Relative Biological Effectivenes, 273
Resistance welding, 121
Rimmed steels, 45
Rockwell, 93

### S

Scatter radiation, 258
Second Critical Angle, 298
Segregation, 20, 198, 232
Shear stress, 239
Shear wave, 295
Shielded metal arc welding (SMAW), 151
Silicon, 9
Smelting, 4
Snell's law, 298
Soldering, 165
Solidification, 14, 15, 17, 19, 20, 28, 30, 58, 152, 171, 175, 176, 194, 198, 202, 235

Solvent removable peneterant, 287
Spheroidal graphite (SG) cast iron, 63
Sponge-iron, 5
Stable, 17, 18, 23, 28, 105, 158, 170, 193, 205, 238, 327
Stainless steels, 65
Strength of material, 87
Stud welding, 163
Subject contrast, 269
Submerged arc welding (SMAW), 160
Suitable light for visual inspection, 250
Sulfur, 8, 37, 43, 65
Superaustenitic stainless steels, 198

### T

Tempering, 10, 70
Tensile test, 93
Ternary phase diagram, 26
The National Board, 340
The National Board Inspection Code, 342
Thermit welding processes, 124
Time temperature transformation (TTT)
diagram, 96
Titanium and titanium alloys, 81
Torsional resistance, 240

### U

Ultrasonic testing, 293 Ultrasonic welding, (USW), 127 Ultraviolet (black) light, 281 Ultraviolet light, 282 Uninvariant equilibrium, 25 Unstable, 17, 23, 187, 188, 222, 242

### V

Velocity of sound (V), 295 Vickers, 93 Visual inspection (VT), 249

### W

Water-washable peneterant, 287 Wavelength ( $\lambda$ ), 295 Weathering steels, 54 Wet magnetic particle inspection, 281 White cast iron, 58 White heart cast iron, 60

### X

X-ray, 255

### Z

Zirconium, 220

2 18/14/Nr