

List of contents

Preface

1 Introduction	1
1.1 Systematics of joining	3
1.2 Joining in the area of conflict between design, material and economic viability	6
1.3 Selection of joining processes	10
2 Joining by welding	13
2.1 Fusion welding using gas	15
2.1.1 Gas fusion welding	15
2.1.1.1 Process principle	15
2.1.1.1.1 Heat generation	17
2.1.1.1.2 Blowpipe	20
2.1.1.1.3 Gas supply	21
2.1.1.1.4 Filler materials	23
2.1.1.1.5 Working techniques	23
2.1.1.2 Materials and sheet thicknesses – characteristic economic data ..	25
2.1.1.3 Mechanisation and automation possibilities	25
2.1.1.4 Application	25
2.1.1.5 Variants	26
2.1.1.6 Special occupational health and safety for gas fusion welding	28
2.1.1.7 Standardisation / guidelines / advanced literature	28
2.2 Fusion welding using electric gas discharge (arc welding)	31
2.2.1 Tungsten inert gas welding (TIG welding)	35
2.2.1.1 Process principle	35
2.2.1.1.1 Tungsten electrode	36
2.2.1.1.2 Shielding gas	38
2.2.1.1.3 Welding torch and hose package	38
2.2.1.1.4 Filler material and filler material supply	40
2.2.1.1.5 Energy source	42
2.2.1.2 Materials and sheet thicknesses – characteristic economic data ..	43
2.2.1.3 Mechanisation and automation possibilities	44
2.2.1.4 Application	45
2.2.1.5 Variants	46
2.2.1.6 Special occupational health and safety	47
2.2.1.7 Standardisation / guidelines / advanced literature	47
2.2.2 Plasma welding	50
2.2.2.1 Process principle	51
2.2.2.1.1 Keyhole effect – Thermal conduction welding	53
2.2.2.1.2 Shielding gas	55
2.2.2.1.3 Torch and hose package	55
2.2.2.1.4 Filler material and filler material supply	56
2.2.2.1.5 Energy source	57

2.2.2.2	Materials and sheet thicknesses – characteristic economic data ..	57
2.2.2.3	Mechanisation and automation possibilities	58
2.2.2.4	Application	58
2.2.2.5	Variants	59
2.2.2.6	Special occupational health and safety	62
2.2.2.7	Standardisation / guidelines / advanced literature	63
2.2.3	Manual metal arc welding	65
2.2.3.1	Process principle	65
2.2.3.1.1	Filler material	66
2.2.3.1.2	Energy source	74
2.2.3.1.3	Miscellaneous equipment	75
2.2.3.2	Materials and sheet thicknesses – characteristic economic data ..	76
2.2.3.3	Mechanisation and automation possibilities	76
2.2.3.4	Application	77
2.2.3.5	Variants	78
2.2.3.6	Special occupational health and safety	79
2.2.3.7	Standardisation / guidelines / advanced literature	79
2.2.4	Gas-shielded metal arc welding (GMA welding)	82
2.2.4.1	Process principle	82
2.2.4.1.1	Material transfer during gas-shielded metal arc welding	83
2.2.4.1.2	Welding parameters and parameter influences	88
2.2.4.1.3	Torch and hose package	92
2.2.4.1.4	Wire feed unit	93
2.2.4.1.5	Energy source	95
2.2.4.1.6	Filler materials and auxiliary materials	96
2.2.4.2	Materials and sheet thicknesses – characteristic economic data	101
2.2.4.3	Mechanisation and automation possibilities	102
2.2.4.4	Application	103
2.2.4.5	Variants	103
2.2.4.6	Special occupational health and safety	109
2.2.4.7	Standardisation / guidelines / advanced literature	109
2.2.5	Electrogas welding	112
2.2.5.1	Process principle	112
2.2.5.1.1	Welding boom, copper shoes and welding feed system	113
2.2.5.1.2	Filler material	114
2.2.5.1.3	Energy source	115
2.2.5.2	Materials and sheet thicknesses – characteristic economic data	115
2.2.5.3	Mechanisation and automation possibilities	116
2.2.5.4	Application	116
2.2.5.5	Variants	116
2.2.5.6	Special occupational health and safety	117
2.2.5.7	Standardisation / guidelines / advanced literature	117
2.2.6	Submerged arc welding	119
2.2.6.1	Process principle	119
2.2.6.1.1	Welding head	122
2.2.6.1.2	Wire feed and wire guiding	122

2.2.6.1.3	Energy source	122
2.2.6.1.4	Filler material	122
2.2.6.2	Materials and sheet thicknesses – characteristic economic data	126
2.2.6.3	Mechanisation and automation possibilities	126
2.2.6.4	Application	127
2.2.6.5	Variants	128
2.2.6.6	Special occupational health and safety	130
2.2.6.7	Standardisation / guidelines / advanced literature	130
2.3	Fusion welding using electric current / resistance heating	133
2.3.1	Electroslag welding	133
2.3.1.1	Process principle	134
2.3.1.1.1	Welding boom, copper shoes and welding feed system	135
2.3.1.1.2	Filler material	136
2.3.1.1.3	Energy source	137
2.3.1.2	Materials and sheet thicknesses – characteristic economic data	137
2.3.1.3	Mechanisation and automation possibilities	137
2.3.1.4	Application	137
2.3.1.5	Variants	138
2.3.1.6	Special occupational health and safety	140
2.3.1.7	Standardisation / guidelines / advanced literature	141
2.4	Fusion welding using radiation (beam welding)	142
2.4.1	Laser beam welding	144
2.4.1.1	Process principle	144
2.4.1.1.1	Beam generation	145
2.4.1.1.2	Beam manipulation and beam forming	149
2.4.1.1.3	Filler materials and auxiliary materials	153
2.4.1.2	Materials and sheet thicknesses – characteristic economic data	154
2.4.1.3	Mechanisation and automation possibilities	155
2.4.1.4	Application	155
2.4.1.5	Variants	157
2.4.1.6	Special occupational health and safety	160
2.4.1.7	Standardisation / guidelines / advanced literature	160
2.4.2	Electron beam welding	163
2.4.2.1	Process principle	163
2.4.2.1.1	Beam generation	163
2.4.2.1.2	Beam manipulation and forming	165
2.4.2.1.3	Installation concepts	166
2.4.2.2	Materials and sheet thicknesses – characteristic economic data	168
2.4.2.3	Mechanisation and automation possibilities	169
2.4.2.4	Application	169
2.4.2.5	Variants	171
2.4.2.6	Special occupational health and safety for electron beam welding	173
2.4.2.7	Standardisation / guidelines / advanced literature	173
2.5	Pressure welding using electric current (resistance welding)	175
2.5.1	Resistance spot welding	176

2.5.1.1	Process principle	176
2.5.1.1.1	Electrode cap shapes and materials	179
2.5.1.1.2	Machines and installations for resistance spot welding	179
2.5.1.2	Materials and sheet thicknesses – characteristic economic data	181
2.5.1.3	Mechanisation and automation possibilities	182
2.5.1.4	Application	183
2.5.1.5	Variants	184
2.5.1.5.1	Projection welding	184
2.5.1.5.2	Roller seam welding	186
2.5.1.6	Special occupational health and safety	187
2.5.1.7	Standardisation / guidelines / advanced literature	187
2.6	Pressure welding by moving mass	191
2.6.1	Friction welding	191
2.6.1.1	Process principle	191
2.6.1.2	Materials and sheet thicknesses – characteristic economic data	192
2.6.1.3	Mechanisation and automation possibilities	193
2.6.1.4	Application	194
2.6.1.5	Variants	194
2.6.1.5.1	Friction stir welding	195
2.6.1.5.2	Ultrasonic welding	196
2.6.1.6	Special occupational health and safety	198
2.6.1.7	Standardisation / guidelines / advanced literature	198
2.7	Pressure welding using electric gas discharge	200
2.7.1	Arc stud welding	200
2.7.1.1	Process principle	200
2.7.1.1.1	Stud welding guns	201
2.7.1.1.2	Power sources	201
2.7.1.1.3	Studs	202
2.7.1.1.4	Filler materials and auxiliary materials	202
2.7.1.2	Materials and sheet thicknesses – characteristic economic data	202
2.7.1.3	Mechanisation and automation possibilities	202
2.7.1.4	Application	203
2.7.1.5	Variants	204
2.7.1.6	Special occupational health and safety	205
2.7.1.7	Standardisation / guidelines / advanced literature	205
2.8	Other processes	206
2.8.1	Pressure butt welding	206
2.8.2	Gas pressure welding	207
2.8.3	Magnetically impelled arc butt welding	207
2.8.4	Flash butt welding	208
2.8.5	Induction and high-frequency welding	209
2.8.6	Aluminothermic welding	211
2.8.7	Explosive welding	213
2.8.8	Magnetic pulse welding	214
2.8.9	Diffusion welding	215

3	Mechanisation and automation	219
3.1	Mechanisation of welding processes	219
3.2	Auxiliary materials and devices for mechanisation and automation	223
3.2.1	Auxiliary jigs for manual and partially mechanised welding	223
3.2.2	Robots	227
3.2.3	Special-purpose machines	230
3.3	Sensor equipment in welding technology	232
3.3.1	Geometry-oriented sensors	232
3.3.2	Process-oriented sensors	234
4	Material behaviour during welding	235
4.1	The welding heat cycle and the influences on it	236
4.2	Iron-based materials (steel)	239
4.2.1	Transformation processes during welding	240
4.2.2	Welding of steel materials	243
4.2.2.1	Welding of non-alloy steels as well of high-strength and higher-strength fine-grain structural steels	245
4.2.2.1.1	Determination of welding parameters	246
4.2.2.1.2	Multipass welding	250
4.2.2.2	Welding of corrosion-resisting steel materials and other alloy steels	251
4.2.2.2.1	Schaeffler diagram	251
4.2.2.3	Selection of welding fillers	257
4.2.2.4	Welding of joints between different steel qualities	258
4.2.2.4.1	Joints between different strength classes	259
4.2.2.4.2	Joints between steels with different chemical compositions	259
4.3	Aluminium alloys	261
4.3.1	Hardenable aluminium alloys	262
4.3.2	Non-hardenable aluminium alloys	265
4.3.3	Welding of aluminium alloys	266
4.3.3.1	Loss of strength in the heat-affected zone	268
4.3.3.2	Influence of the oxide coat	269
4.3.3.3	Pore formation	270
4.3.3.4	Hot cracks	272
4.4	Standardisation / guidelines / advanced literature	273
5	Design	276
5.1	Requirements on the design	276
5.1.1	Design requirements in relation to strength and load-bearing capacity aspects (design appropriate for stresses)	277
5.1.1.1	Notch effect	278
5.1.1.2	Residual stresses	282
5.1.1.3	Multiaxial stress conditions	284
5.1.1.4	Load situation	286
5.1.2	Design requirements from the joining process (design appropriate for fabrication)	288

5.1.2.1	Arc welding	289
5.1.2.2	Beam welding	293
5.1.2.3	Resistance welding	295
5.1.3	Design requirements for mechanisation and automation (also appropriate for fabrication)	297
5.1.4	Design requirements with regard to the material	301
5.1.5	Design requirements with regard to the testability	303
5.2	Design and calculation methods	305
5.2.1	Estimation of the stresses with static and quasi-static loads	307
5.2.2	Estimation of the stress-bearing capacity with cyclic loads	309
5.3	Documentation on drawings and welding plans	311
5.4	Damage analysis	313
5.5	Standardisation / guidelines / advanced literature	316
6	Quality assurance and testing	318
6.1	Quality assurance in welding technology	318
6.1.1	Quality-monitoring sensor equipment	321
6.2	Imperfections / welding defects	324
6.2.1	Types of imperfections	325
6.2.1.1	Surface imperfections	325
6.2.1.2	Internal imperfections	325
6.3	Destructive testing	328
6.3.1	Component tests	328
6.3.2	Standard testing procedures	329
6.3.2.1	Tensile test	329
6.3.2.2	Pendulum impact test	331
6.3.2.3	Metallography / transverse section	333
6.4	Non-destructive testing procedures	334
6.4.1	Visual inspection	335
6.4.2	Penetrant test	335
6.4.3	Magnetic particle test	336
6.4.4	Radiographic test	338
6.4.5	Ultrasonic test	339
6.5	Standardisation / guidelines	340
7	Occupational health and safety in joining technology	344
7.1	Hazards	344
7.2	Protective measures	346
7.3	Standardisation / guidelines / advanced literature	349
8	Surface welding	350
8.1	Standardisation / guidelines / advanced literature	351
9	Brazing	352
9.1	Introduction	352
9.2	Brazing/soldering process	354
9.3	Brazing solders and their classes	358

9.3.1 Solders	360
9.3.2 Brazing solders and high-temperature brazing solders	360
9.4 Fluxes	361
9.5 Process variants	363
9.5.1 Joining brazing using gas / flame brazing	364
9.5.2 Resistance brazing/soldering	366
9.5.3 Induction brazing	367
9.5.4 Furnace brazing	368
9.5.5 Brazing with welding processes as the heat source	370
9.6 Design-related notes	371
9.7 Occupational health and safety	373
9.8 Standardisation / guidelines / advanced literature	373
10 Adhesive bonding	375
10.1 Introduction	375
10.2 Adhesive bonding process	375
10.3 Properties of adhesive-bonded joints	377
10.3.1 Advantages and disadvantages	378
10.3.2 Functions	381
10.4 Adhesives	386
10.4.1 Hot melt adhesives	388
10.4.2 Plastisols	389
10.4.3 Pressure-sensitive adhesives	389
10.4.4 Acrylate adhesives	390
10.4.5 Epoxy adhesives	392
10.4.6 Polyurethane adhesives	393
10.5 Wetting and adhesion	395
10.6 Adhesive bonding process	397
10.6.1 Surface treatment	397
10.6.2 Surfaces of metals	398
10.6.3 Procedures for surface preparation	400
10.6.4 Procedures for surface pretreatment	401
10.6.5 Procedures for surface posttreatment	402
10.6.6 Dispensing, application and automation	402
10.6.7 Curing process	405
10.7 Design	406
10.7.1 Requirements on the design	406
10.7.2 Calculation methods	408
10.8 Quality assurance and testing	409
10.8.1 Quality assurance in adhesive bonding technology	409
10.8.2 Destructive testing	412
10.9 Occupational health and safety and environmental protection in adhesive bonding technology	414
11 Glossary / definitions of terms	416
12 Literature	426