

# MMPDS-11 COMPLETE HANDBOOK

## PART 1 - Table of Contents

Foreword . . . . .	.i
Explanation of Numerical Code . . . . .	iii
Registered Trademarks . . . . .	v
CHAPTER 1 GENERAL . . . . .	C1-1
1.1 PURPOSE AND USE OF DOCUMENT . . . . .	C1-1
1.1.1 INTRODUCTION . . . . .	C1-1
1.1.2 SCOPE OF HANDBOOK . . . . .	C1-1
1.2 NOMENCLATURE . . . . .	C1-3
1.2.1 SYMBOLS AND DEFINITIONS . . . . .	C1-3
1.2.2 INTERNATIONAL SYSTEM OF UNITS . . . . .	C1-3
1.3 COMMONLY USED FORMULAS . . . . .	C1-5
1.3.1 GENERAL . . . . .	C1-5
1.3.2 SIMPLE UNIT STRESSES . . . . .	C1-5
1.3.3 COMBINED STRESSES (SEE SECTION 1.5.3.5) . . . . .	C1-5
1.3.4 DEFLECTIONS (AXIAL) . . . . .	C1-5
1.3.5 DEFLECTIONS (BENDING) . . . . .	C1-5
1.3.6 DEFLECTIONS (TORSION) . . . . .	C1-6
1.3.7 BIAXIAL ELASTIC DEFORMATION . . . . .	C1-6
1.3.8 BASIC COLUMN FORMULAS . . . . .	C1-6
1.3.9 INELASTIC STRESS-STRAIN RESPONSE . . . . .	C1-7
1.4 BASIC PRINCIPLES . . . . .	C1-9
1.4.1 GENERAL . . . . .	C1-9
1.4.1.1 Basis . . . . .	C1-9
1.4.1.2 Statistically Calculated Values . . . . .	C1-10
1.4.1.3 Ratioed Values . . . . .	C1-10
1.4.1.4 Choosing Appropriate Allowables . . . . .	C1-10
1.4.2 STRESS . . . . .	C1-10
1.4.3 STRAIN . . . . .	C1-10
1.4.3.1 Poisson's Ratio Effect . . . . .	C1-11
1.4.3.2 Shear Strain . . . . .	C1-11
1.4.3.3 Strain Rate . . . . .	C1-11
1.4.3.4 Elongation and Reduction of Area . . . . .	C1-11
1.4.4 INTRODUCTION TO STRESS STRAIN CURVES IN MMPDS . . . . .	C1-11
1.4.4.1 The One Parameter Ramberg-Osgood Stress Strain Curve . . . . .	C1-14
1.4.4.2 The Two Parameter Bron Stress Strain Curve . . . . .	C1-16
1.4.4.3 Tensile Properties . . . . .	C1-17
1.4.4.4 Modulus of Elasticity (E) . . . . .	C1-20
1.4.4.5 Tensile Proportional Limit Stress (F <sub>tp</sub> ) . . . . .	C1-21
1.4.4.6 Tensile Yield Stress (TYS or F <sub>ty</sub> ) . . . . .	C1-22
1.4.4.7 Tensile Ultimate Stress (TUS or F <sub>tu</sub> ) . . . . .	C1-22

# MMPDS-11 COMPLETE HANDBOOK

## PART 1 - Table of Contents

1.4.4.8 Elongation (e)	C1-22
1.4.4.9 Reduction of Area (RA)	C1-22
1.4.4.10 Design Stress-Strain Curves	C1-22
1.4.4.11 Dynamic Modulus (ED)	C1-23
1.4.5 COMPRESSIVE PROPERTIES	C1-24
1.4.5.1 Compressive Ultimate Stress (Fcu)	C1-24
1.4.5.2 Compressive Yield Stress (CYS or Fcy)	C1-24
1.4.6 SHEAR PROPERTIES	C1-24
1.4.6.1 Modulus of Rigidity (G)	C1-24
1.4.6.2 Ultimate and Yield Stresses in Shear (SUS or Fsu) and (SYS or Fsy)	C1-25
1.4.7 BEARING PROPERTIES	C1-26
1.4.7.1 Bearing Yield (BYS or Fbry) and Ultimate (BUS or Fbru) Stress	C1-27
1.4.7.2 Bearing Load Orientation	C1-27
1.4.8 TEMPERATURE EFFECTS	C1-29
1.4.8.1 Low Temperature	C1-29
1.4.8.2 Elevated Temperature	C1-29
1.4.9 FATIGUE PROPERTIES	C1-31
1.4.9.1 Terminology	C1-31
1.4.9.2 Graphical Display of Fatigue Data	C1-31
1.4.10 METALLURGICAL INSTABILITY	C1-33
1.4.11 BIAxIAL PROPERTIES	C1-33
1.4.11.1 Biaxial Modulus of Elasticity	C1-34
1.4.11.2 Biaxial Yield Stress	C1-35
1.4.11.3 Biaxial Ultimate Stress	C1-35
1.4.12 FRACTURE TOUGHNESS	C1-35
1.4.12.1 Brittle Fracture	C1-36
1.4.12.2 Brittle Fracture Analysis	C1-36
1.4.12.3 Critical Plane-Strain Fracture Toughness	C1-37
1.4.12.4 Fracture in Plane-Stress and Transitional-Stress States	C1-38
1.4.12.5 Apparent Fracture Toughness Values for Plane-Stress and Transitional-Stress States	C1-39
1.4.12.6 Crack Resistance (R-Curve)	C1-40
1.4.13 FATIGUE CRACK GROWTH	C1-44
1.4.13.1 Fatigue Crack Growth Rate Testing	C1-44
1.4.13.2 Fatigue Crack Growth Analysis	C1-45
1.4.13.3 Fatigue Crack Growth Data Presentation	C1-46
1.4.14. Use of Values for Heat Treat by User Materials	C1-47
1.5 TYPES OF FAILURES	C1-49
1.5.1 GENERAL	C1-49
1.5.2 MATERIAL FAILURES	C1-49
1.5.2.1 Direct Tension or Compression	C1-49
1.5.2.2 Shear	C1-49

# MMPDS-11 COMPLETE HANDBOOK

## PART 1 - Table of Contents

1.5.2.3 Bearing . . . . .	C1-49
1.5.2.4 Bending . . . . .	C1-49
1.5.2.5 Failure Due to Stress Concentrations . . . . .	C1-50
1.5.2.6 Failure From Combined Stresses . . . . .	C1-50
1.5.3 INSTABILITY FAILURES . . . . .	C1-50
1.5.3.1 Instability Failures Under Compression . . . . .	C1-50
1.5.3.2 Instability Failures Under Bending. . . . .	C1-50
1.5.3.3 Instability Failures Under Torsion . . . . .	C1-50
1.5.3.4 Failure Under Combined Loadings . . . . .	C1-50
1.6 COLUMNS . . . . .	C1-51
1.6.1 GENERAL . . . . .	C1-51
1.6.2 PRIMARY INSTABILITY FAILURES . . . . .	C1-51
1.6.2.1 Columns With Stable Sections . . . . .	C1-51
1.6.2.2 Maximum Column Stress FCO for Stable Cross Sections. . . . .	C1-53
1.6.2.3 Torsional Instability . . . . .	C1-53
1.6.2.4 Other Considerations . . . . .	C1-54
1.6.3 LOCAL INSTABILITY FAILURES . . . . .	C1-54
1.6.3.1 Crippling Stress (Fcc) . . . . .	C1-54
1.6.4 CORRECTION OF COLUMN TEST RESULTS. . . . .	C1-54
1.6.4.1 Nature of “Short Column Curve” . . . . .	C1-54
1.6.4.2 Local Failure . . . . .	C1-54
1.6.4.3 Reduction of Column Test Results on Aluminum and Magnesium Alloys to Standard Material . . . . .	C1-54
1.6.4.4 Reduction of Column Test Results to Standard Material-Alternate Method . . . . .	C1-60
1.6.5 COMPACT SECTION BUCKLING AND Et ESTIMATES . . . . .	C1-62
1.6.5.1 Column Curve Comparison Criteria . . . . .	C1-64
1.6.5.2 Compressive Stress Strain and Et Figure Footnotes. . . . .	C1-64
1.7 THIN-WALLED AND STIFFENED THIN-WALLED SECTIONS . . . . .	C1-65
1.8 ALLOWABLES-BASED FLOW STRESS FOR NONLINEAR STATIC ANALYSIS. . . . .	C1-67
1.8.1 INTRODUCTION . . . . .	C1-67
1.8.2 DETAILED PROCEDURE . . . . .	C1-67
1.8.3 REPORTING REQUIREMENTS . . . . .	C1-70
1.9 ESTIMATION OF AVERAGE TENSILE PROPERTIES FROM A- AND B-BASIS DESIGN ALLOWABLES . . . . .	C1-71
1.9.1 INTRODUCTION . . . . .	C1-71
1.9.2 GENERAL TRENDS . . . . .	C1-71
REFERENCES . . . . .	REF-C1-1
CHAPTER 2 STEEL ALLOYS . . . . .	C2-1
2.1 GENERAL . . . . .	C2-1
2.1.1 ALLOY INDEX . . . . .	C2-1
2.1.2 MATERIAL PROPERTIES . . . . .	C2-2

# MMPDS-11 COMPLETE HANDBOOK

## PART 1 - Table of Contents

2.1.2.1 Mechanical Properties . . . . .	C2-3
2.1.2.2 Physical Properties . . . . .	C2-6
2.1.3 ENVIRONMENTAL CONSIDERATIONS . . . . .	C2-9
2.1.4 OBSOLETE ALLOYS, HEAT TREATMENTS, AND PRODUCT FORMS . . . . .	C2-9
2.2 CARBON STEELS . . . . .	C2-13
2.2.0 COMMENTS ON CARBON STEELS . . . . .	C2-13
2.2.0.1 Metallurgical Considerations . . . . .	C2-13
2.2.0.2 Manufacturing Considerations . . . . .	C2-13
2.2.0.3 Environmental Considerations . . . . .	C2-14
2.2.1 AISI 1025 . . . . .	C2-15
2.2.1.0 Comments and Properties. . . . .	C2-15
2.3 LOW-ALLOY STEELS (AISİ GRADES AND PROPRIETARY GRADES) . . . . .	C2-19
2.3.0 COMMENTS ON LOW-ALLOY STEELS (AISİ AND PROPRIETARY GRADES). . . . .	C2-19
2.3.0.1 Metallurgical Considerations . . . . .	C2-19
2.3.0.2 Manufacturing Conditions . . . . .	C2-19
2.3.0.3 Environmental Considerations . . . . .	C2-22
2.3.1 SPECIFIC ALLOYS. . . . .	C2-23
2.3.1.0 Comments and Properties. . . . .	C2-23
2.3.1.1 AISİ Low-Alloy Steels. . . . .	C2-23
2.3.1.2 AISİ 4130 and 8630 Steels . . . . .	C2-23
2.3.1.3 AISİ 4340 Steel . . . . .	C2-23
2.3.1.4 300M Steel . . . . .	C2-23
2.3.1.5 D6AC Steel . . . . .	C2-23
2.4 INTERMEDIATE ALLOY STEELS . . . . .	C2-75
2.4.0 Comments on Intermediate Alloy Steels . . . . .	C2-75
2.4.0.1 Metallurgical Considerations . . . . .	C2-75
2.4.1 5CR-MO-V . . . . .	C2-75
2.4.1.0 Comments and Properties. . . . .	C2-75
2.4.1.1 Heat-Treated Condition . . . . .	C2-79
2.4.2 9Ni-4Co-0.20C. . . . .	C2-83
2.4.2.0 Comments and Properties. . . . .	C2-83
2.4.2.1 Heat-Treated Condition . . . . .	C2-85
2.4.3 9Ni-4Co-0.30C. . . . .	C2-88
2.4.3.0 Comments and Properties. . . . .	C2-88
2.4.3.1 Heat-Treated Condition . . . . .	C2-90
2.5 HIGH-ALLOY STEELS . . . . .	C2-99
2.5.0 COMMENTS ON HIGH-ALLOY STEELS . . . . .	C2-99
2.5.0.1 Metallurgical Considerations . . . . .	C2-99
2.5.0.2 Environmental Considerations . . . . .	C2-99
2.5.1 18 NI MARAGING STEELS . . . . .	C2-101

# MMPDS-11 COMPLETE HANDBOOK

## PART 1 - Table of Contents

2.5.1.0 Comments and Properties . . . . .	C2-101
2.5.1.1 Maraged Condition (aged at 900°F) . . . . .	C2-101
2.5.2 AF1410 . . . . .	C2-110
2.5.2.0 Comments and Properties . . . . .	C2-110
2.5.2.1 Heat-Treated Condition . . . . .	C2-112
2.5.3 AERMET 100 . . . . .	C2-113
2.5.3.0 Comments and Properties . . . . .	C2-113
2.5.3.1 280-300 ksi Heat-Treated Condition . . . . .	C2-115
2.5.3.2 290-310 ksi Heat-Treated Condition . . . . .	C2-117
2.5.4 FERRIUM S53 . . . . .	C2-119
2.5.4.0 Comments and Properties . . . . .	C2-119
2.5.4.1 Heat Treated Condition . . . . .	C2-122
2.5.5 FERRIUM M54 . . . . .	C2-131
2.5.5.0 Comments and Properties . . . . .	C2-131
2.5.5.1 Aged at 960°F Condition . . . . .	C2-134
2.6 PRECIPITATION- AND TRANSFORMATION-HARDENING STEELS (STAINLESS) . . . . .	C2-137
2.6.0 COMMENTS ON PRECIPITATION AND TRANSFORMATION-HARDENING STEELS (STAINLESS) . . . . .	C2-137
2.6.0.1 Metallurgical Considerations . . . . .	C2-137
2.6.0.2 Manufacturing Considerations . . . . .	C2-137
2.6.0.3 Environmental Considerations . . . . .	C2-137
2.6.1 AM-350 . . . . .	C2-137
2.6.1.0 Comments and Properties . . . . .	C2-137
2.6.1.1 SCT 850 Condition . . . . .	C2-140
2.6.2 AM-355 . . . . .	C2-144
2.6.2.0 Comments and Properties . . . . .	C2-144
2.6.2.1 SCT Condition . . . . .	C2-148
2.6.3 CUSTOM 450 . . . . .	C2-150
2.6.3.0 Comments and Properties . . . . .	C2-150
2.6.3.1 H900 Condition . . . . .	C2-154
2.6.3.2 H1050 Condition . . . . .	C2-158
2.6.4 CUSTOM 455 . . . . .	C2-162
2.6.4.0 Comments and Properties . . . . .	C2-162
2.6.4.1 H950 Condition . . . . .	C2-165
2.6.4.2 H1000 Condition . . . . .	C2-170
2.6.5 CUSTOM 465 . . . . .	C2-173
2.6.5.0 Comments and Properties . . . . .	C2-173
2.6.5.1 H950 and H1000 Condition . . . . .	C2-176
2.6.6 PH13-8Mo . . . . .	C2-179
2.6.6.0 Comments and Properties . . . . .	C2-179
2.6.6.1 H950 and H1000 Conditions . . . . .	C2-184
2.6.6.2 Extra-High Toughness H1000 Conditions . . . . .	C2-190

# MMPDS-11 COMPLETE HANDBOOK

## PART 1 - Table of Contents

2.6.7 15-5PH . . . . .	C2-198
2.6.7.0 Comments and Properties . . . . .	C2-198
2.6.7.1 Various Heat-Treated Conditions . . . . .	C2-203
2.6.7.2 H1025 Condition . . . . .	C2-206
2.6.7.3 H1150 Condition . . . . .	C2-211
2.6.8 PH15-7Mo . . . . .	C2-212
2.6.8.0 Comments and Properties . . . . .	C2-212
2.6.8.1 TH1050 Condition . . . . .	C2-215
2.6.9 17-4PH . . . . .	C2-224
2.6.9.0 Comments and Properties . . . . .	C2-224
2.6.9.1 H900 Condition . . . . .	C2-231
2.6.9.2 Various Heat Treat Conditions . . . . .	C2-236
2.6.9.3 H1000 Condition . . . . .	C2-238
2.6.9.4 H1025 Condition . . . . .	C2-239
2.6.9.5 H1100 Condition . . . . .	C2-240
2.6.9.6 H1150 Condition . . . . .	C2-241
2.6.10 17-7PH . . . . .	C2-242
2.6.10.0 Comments and Properties . . . . .	C2-242
2.6.10.1 TH1050 Condition . . . . .	C2-245
2.6.11 HSL180 (12.5CR-1.0 NI-15.5CO-2.0MO) . . . . .	C2-249
2.6.11.0 Comments and Properties . . . . .	C2-249
2.6.11.1 Austenitized and Tempered Condition . . . . .	C2-251
2.6.12 MLX17 . . . . .	C2-256
2.6.12.0 Comments and Properties . . . . .	C2-256
2.6.12.1 H950 Condition . . . . .	C2-259
2.6.12.2 H1000 Condition . . . . .	C2-262
2.6.13 MLX19 . . . . .	C2-265
2.6.13.0 Comments and Properties . . . . .	C2-265
2.6.13.1 H950 Condition . . . . .	C2-268
2.7 AUSTENITIC STAINLESS STEELS . . . . .	C2-271
2.7.0 COMMENTS ON AUSTENITIC STAINLESS STEEL . . . . .	C2-271
2.7.0.1 Metallurgical Considerations . . . . .	C2-271
2.7.0.2 Manufacturing Considerations . . . . .	C2-271
2.7.0.3 Environmental Considerations . . . . .	C2-272
2.7.1 AISI 301 AND RELATED 300 SERIES STAINLESS STEELS . . . . .	C2-273
2.7.1.0 Comments and Properties . . . . .	C2-273
2.7.1.1 Solution Heat Treated Condition . . . . .	C2-280
2.7.1.2 ¼ Hard Condition . . . . .	C2-282
2.7.1.3 ½ Hard Condition . . . . .	C2-283
2.7.1.4 ¾ Hard Condition . . . . .	C2-286
2.7.1.5 Full-Hard Condition . . . . .	C2-287

# MMPDS-11 COMPLETE HANDBOOK

## PART 1 - Table of Contents

2.8 ELEMENT PROPERTIES . . . . .	C2-293
2.8.1 BEAMS . . . . .	C2-293
2.8.1.1 Simple Beams . . . . .	C2-293
2.8.1.2 Built-Up Beams . . . . .	C2-293
2.8.1.3 Thin-Web Beams . . . . .	C2-293
2.8.2 COLUMNS . . . . .	C2-296
2.8.2.1 General . . . . .	C2-296
2.8.2.2 Effects of Welding . . . . .	C2-296
2.8.3 TORSION . . . . .	C2-297
2.8.3.1 General . . . . .	C2-297
2.8.3.2 Torsion Properties . . . . .	C2-297
REFERENCES . . . . .	REF-C2-1
CHAPTER 3 - ALUMINUM ALLOYS . . . . .	C3-1
3.1. GENERAL . . . . .	C3-1
3.1.1. ALUMINUM ALLOY INDEX . . . . .	C3-1
3.1.2. MATERIAL PROPERTIES. . . . .	C3-2
3.1.2.1. Mechanical Properties . . . . .	C3-7
3.1.2.2. Physical Properties. . . . .	C3-34
3.1.2.3. Corrosion Resistance . . . . .	C3-34
3.1.3. MANUFACTURING CONSIDERATIONS . . . . .	C3-42
3.1.3.1. Avoiding Stress Corrosion Cracking . . . . .	C3-42
3.1.3.2. Cold-Formed, Heat-Treatable Aluminum Alloys . . . . .	C3-42
3.1.3.3. Dimensional Changes. . . . .	C3-42
3.1.3.4. Welding . . . . .	C3-43
3.1.4. OBSOLETE ALLOYS, TEMPERS, AND PRODUCT FORMS. . . . .	C3-47
3.1.5. STABILIZED SPECIFICATIONS . . . . .	C3-49
3.2. 2000 SERIES WROUGHT ALLOYS . . . . .	C3-51
3.2.1. 2013 ALLOY. . . . .	C3-51
3.2.1.0. Comments and Properties . . . . .	C3-51
3.2.1.1. T6511 Temper . . . . .	C3-53
3.2.2. 2014 ALLOY. . . . .	C3-68
3.2.2.0. Comments and Properties . . . . .	C3-68
3.2.2.1. T6, T62, T651, T652, T6510, and T6511 Temper. . . . .	C3-78
3.2.3. 2017 ALLOY. . . . .	C3-102
3.2.3.0. Comments and Properties . . . . .	C3-102
3.2.3.1. T4, T451, and T42 Temper. . . . .	C3-105
3.2.4 2024 ALLOY . . . . .	C3-106
3.2.4.0 Comments and Properties. . . . .	C3-106
3.2.4.1 T3, T351, T3510, T3511, T4, and T42 Temper . . . . .	C3-126
3.2.4.2 T361 (supersedes T36) Temper. . . . .	C3-162
3.2.4.3 T62 and T72 Temper . . . . .	C3-162
3.2.4.4 T81, T851, T852, T8510, and T8511 Temper. . . . .	C3-169
3.2.4.5 T861 (supersedes T86) Temper. . . . .	C3-182

# MMPDS-11 COMPLETE HANDBOOK

## PART 1 - Table of Contents

3.2.5 2025 ALLOY . . . . .	C3-191
3.2.5.0 Comments and Properties. . . . .	C3-191
3.2.6 2026 ALLOY . . . . .	C3-194
3.2.6.0 Comments and Properties. . . . .	C3-194
3.2.7 2027 ALLOY . . . . .	C3-196
3.2.7.0 Comments and Properties. . . . .	C3-196
3.2.7.1 T351 Temper . . . . .	C3-199
3.2.7.2 T3511 Temper . . . . .	C3-203
3.2.8 2050 ALLOY . . . . .	C3-205
3.2.8.0 Comments and Properties. . . . .	C3-205
3.2.8.1 T84 Temper . . . . .	C3-214
3.2.9 CLAD 2056 ALLOY . . . . .	C3-224
3.2.9.0 Comments and Properties. . . . .	C3-224
3.2.10 2090 ALLOY . . . . .	C3-230
3.2.10.0 Comments and Properties . . . . .	C3-230
3.2.10.1 T83 Temper . . . . .	C3-232
3.2.11 2098 ALLOY . . . . .	C3-233
3.2.11.0 Comments and Properties . . . . .	C3-233
3.2.11.1 T82P Temper . . . . .	C3-237
3.2.12 2099 ALLOY . . . . .	C3-243
3.2.12.0 Comments and Properties . . . . .	C3-243
3.2.12.1 T86 Temper . . . . .	C3-247
3.2.12.2 T83 Temper . . . . .	C3-249
3.2.12.3 T81 Temper . . . . .	C3-255
3.2.13 2124 ALLOY . . . . .	C3-257
3.2.13.0 Comments and Properties . . . . .	C3-257
3.2.13.1 T851 Temper . . . . .	C3-259
3.2.14 2195 ALLOY . . . . .	C3-275
3.2.14.0 Comments and Properties . . . . .	C3-275
3.2.14.1 T8, T82 Temper . . . . .	C3-281
3.2.15 2196 ALLOY . . . . .	C3-286
3.2.15.0 Comments and Properties . . . . .	C3-286
3.2.15.1 T8511 Temper . . . . .	C3-289
3.2.16 2198 ALLOY . . . . .	C3-291
3.2.16.0 Comments and Properties . . . . .	C3-291
3.2.16.1 T8 Temper . . . . .	C3-294
3.2.17 2219 ALLOY . . . . .	C3-304
3.2.17.0 Comments and Properties . . . . .	C3-304
3.2.17.1 T62 Temper . . . . .	C3-311
3.2.17.2 T81 and T851X Tempers . . . . .	C3-314
3.2.17.3 T852 Temper . . . . .	C3-322
3.2.17.4 T87 Temper . . . . .	C3-325

# MMPDS-11 COMPLETE HANDBOOK

## PART 1 - Table of Contents

3.2.18 2297 ALLOY . . . . .	C3-330
3.2.18.0 Comments and Properties . . . . .	C3-330
3.2.18.1 T87 Temper . . . . .	C3-333
3.2.19 2397 ALLOY . . . . .	C3-339
3.2.19.0 Comments and Properties . . . . .	C3-339
3.2.20 2424 ALLOY . . . . .	C3-342
3.2.20.0 Comments and Properties . . . . .	C3-342
3.2.21 2519 ALLOY . . . . .	C3-345
3.2.21.0 Comments and Properties . . . . .	C3-345
3.2.21.1 T87 Temper . . . . .	C3-347
3.2.22 2524 ALLOY . . . . .	C3-348
3.2.22.0 Comments and Properties . . . . .	C3-348
3.2.22.1 T3 Temper . . . . .	C3-350
3.2.23 2618 ALLOY . . . . .	C3-352
3.2.23.0 Comments and Properties . . . . .	C3-352
3.2.23.1 T61 Temper . . . . .	C3-356
3.2.24 2624 ALLOY . . . . .	C3-362
3.2.24.0 Comments and Properties . . . . .	C3-362
3.2.24.1 T39 Temper . . . . .	C3-365
3.2.24.2 T351 Temper . . . . .	C3-368
3.2.25 2055 ALLOY . . . . .	C3-371
3.2.25.0 Comments and Properties . . . . .	C3-371
3.2.25.1 T84 Temper . . . . .	C3-373
3.2.26 2824 ALLOY . . . . .	C3-379
3.2.26.0 Comments and Properties . . . . .	C3-379
3.2.26.1 T3511 Temper . . . . .	C3-382
3.2.27 2029 Alloy . . . . .	C3-386
3.2.27.0 Comments and Properties . . . . .	C3-386
3.2.27.1 T8 Temper . . . . .	C3-389
3.3 3000 SERIES WROUGHT ALLOYS . . . . .	C3-395
3.4 4000 SERIES WROUGHT ALLOYS . . . . .	C3-395
3.5 5000 SERIES WROUGHT ALLOYS . . . . .	C3-395
3.5.1 5052 ALLOY . . . . .	C3-395
3.5.1.0 Comments and Properties . . . . .	C3-395
3.5.1.1 O-Temper . . . . .	C3-399
3.5.1.2 H32 Temper . . . . .	C3-401
3.5.1.3 H34 Temper . . . . .	C3-401
3.5.1.4 H36 Temper . . . . .	C3-404
3.5.1.5 H38 Temper . . . . .	C3-404
3.5.2 5083 ALLOY . . . . .	C3-407
3.5.2.0 Comments and Properties . . . . .	C3-407
3.5.2.1 O Temper . . . . .	C3-412

# MMPDS-11 COMPLETE HANDBOOK

## PART 1 - Table of Contents

3.5.3 5086 ALLOY . . . . .	C3-414
3.5.3.0 Comments and Properties. . . . .	C3-414
3.5.3.1 O Temper . . . . .	C3-417
3.5.3.2 H32 Temper . . . . .	C3-419
3.5.3.3 H34 Temper . . . . .	C3-421
3.5.3.4 H36 Temper . . . . .	C3-423
3.5.3.5 H38 Temper . . . . .	C3-424
3.5.3.6 H111 Temper . . . . .	C3-424
3.5.3.7 H112 Temper . . . . .	C3-424
3.5.4 5454 ALLOY . . . . .	C3-425
3.5.4.0 Comments and Properties. . . . .	C3-425
3.5.4.1 O Temper . . . . .	C3-428
3.5.4.2 H32 Temper . . . . .	C3-428
3.5.4.3 H34 Temper . . . . .	C3-429
3.5.5 5456 ALLOY . . . . .	C3-431
3.5.5.0 Comments and Properties. . . . .	C3-431
3.5.5.1 O Temper . . . . .	C3-435
3.5.5.2 H111 Temper . . . . .	C3-436
3.5.5.3 H112 Temper . . . . .	C3-437
3.5.5.4 H321 Temper . . . . .	C3-437
3.6 6000 SERIES WROUGHT ALLOYS . . . . .	C3-439
3.6.1 6013 ALLOY . . . . .	C3-439
3.6.1.0 Comments and Properties. . . . .	C3-439
3.6.1.1 T6 Temper . . . . .	C3-441
3.6.2 6061 ALLOY . . . . .	C3-442
3.6.2.0 Comments and Properties. . . . .	C3-442
3.6.2.1 T4, T42, T451, T4510, and T4511 Tempers . . . . .	C3-454
3.6.2.2 T6, T62, T651, T652, T6510, and T6511 Tempers . . . . .	C3-454
3.6.3 6151 ALLOY . . . . .	C3-471
3.6.3.0 Comments and Properties. . . . .	C3-471
3.6.3.1 T6 Temper . . . . .	C3-471
3.6.4 6156 ALLOY . . . . .	C3-474
3.6.4.0 Comments and Properties. . . . .	C3-474
3.6.4.1 T62 Temper . . . . .	C3-476
3.7 7000 SERIES WROUGHT ALLOYS . . . . .	C3-479
3.7.1 7010 ALLOY . . . . .	C3-479
3.7.1.0 Comments and Properties. . . . .	C3-479
3.7.1.1 T7451 Temper . . . . .	C3-482
3.7.1.2 T7651 Temper . . . . .	C3-485
3.7.2 7037 ALLOY . . . . .	C3-487
3.7.2.0 Comments and Properties. . . . .	C3-487
3.7.2.1 T7452 Temper . . . . .	C3-490

# MMPDS-11 COMPLETE HANDBOOK

## PART 1 - Table of Contents

3.7.3 7040 ALLOY . . . . .	C3-496
3.7.3.0 Comments and Properties. . . . .	C3-496
3.7.4 7049/7149 ALLOY . . . . .	C3-500
3.7.4.0 Comments and Properties. . . . .	C3-500
3.7.4.1 T73 and T73511 Tempers. . . . .	C3-505
3.7.5 7050 ALLOY . . . . .	C3-517
3.7.5.0 Comments and Properties. . . . .	C3-517
3.7.5.1 T73510 and T73511 Tempers . . . . .	C3-528
3.7.5.2 T74, T7451, and T7452 Tempers . . . . .	C3-532
3.7.5.3 T76510 and T76511 Tempers . . . . .	C3-564
3.7.6 7055 ALLOY . . . . .	C3-569
3.7.6.0 Comments and Properties. . . . .	C3-569
3.7.6.1 T74511 Temper . . . . .	C3-574
3.7.6.2 T76511 Temper . . . . .	C3-581
3.7.6.3 T7751 and T77511 Tempers. . . . .	C3-581
3.7.7 7056 ALLOY . . . . .	C3-584
3.7.7.0 Comments and Properties. . . . .	C3-584
3.7.7.1 T7651 Temper . . . . .	C3-587
3.7.8 7068 ALLOY . . . . .	C3-591
3.7.8.0 Comments and Properties. . . . .	C3-591
3.7.8.1 T6511 Temper . . . . .	C3-593
3.7.9 7075 ALLOY . . . . .	C3-598
3.7.9.0 Comments and Properties. . . . .	C3-598
3.7.9.1 T6, T651, T652, T6510, T6511 Temper. . . . .	C3-620
3.7.9.2 T73, T7351, T7352, T73510, T73511 Tempers . . . . .	C3-656
3.7.10 7085 ALLOY. . . . .	C3-674
3.7.10.0 Comments and Properties . . . . .	C3-674
3.7.10.1 T7451 Temper . . . . .	C3-682
3.7.10.2 T7651 Temper . . . . .	C3-684
3.7.10.3 T7452 Temper . . . . .	C3-686
3.7.11 7136 ALLOY. . . . .	C3-706
3.7.11.0 Comments and Properties . . . . .	C3-706
3.7.11.1 T76511 Temper. . . . .	C3-708
3.7.12 7140 ALLOY. . . . .	C3-713
3.7.12.0 Comments and Properties . . . . .	C3-713
3.7.12.1 T7451 Temper . . . . .	C3-717
3.7.12.2 T7651 Temper . . . . .	C3-720
3.7.13 7150 ALLOY. . . . .	C3-728
3.7.13.0 Comments and Properties . . . . .	C3-728
3.7.13.1 T6151 and T61511 Tempers . . . . .	C3-734
3.7.13.2 T7751 and T77511 Tempers . . . . .	C3-736

# MMPDS-11 COMPLETE HANDBOOK

## PART 1 - Table of Contents

3.7.14 7175 ALLOY . . . . .	C3-741
3.7.14.0 Comments and Properties . . . . .	C3-741
3.7.14.1 T73511 Temper . . . . .	C3-746
3.7.14.2 T74 and T7452 Tempers. . . . .	C3-751
3.7.15 7249 ALLOY . . . . .	C3-756
3.7.15.0 Comments and Properties . . . . .	C3-756
3.7.15.1 T7452 Temper . . . . .	C3-760
3.7.15.2 T76511 Temper. . . . .	C3-762
3.7.16 7255 ALLOY . . . . .	C3-764
3.7.16.0 Comments and Properties . . . . .	C3-764
3.7.16.1 T7751 Temper . . . . .	C3-766
3.7.17 7349 ALLOY . . . . .	C3-768
3.7.17.0 Comments and Properties . . . . .	C3-768
3.7.17.1 T76511 Temper. . . . .	C3-770
3.7.18 7449 ALLOY . . . . .	C3-772
3.7.18.0 Comments and Properties . . . . .	C3-772
3.7.18.1 T7651 Temper . . . . .	C3-779
3.7.18.2 T7951 Temper . . . . .	C3-782
3.7.18.3 T79511 Temper. . . . .	C3-785
3.7.19 7475 ALLOY . . . . .	C3-788
3.7.19.0 Comments and Properties . . . . .	C3-788
3.7.19.1 T61 and T651 Tempers . . . . .	C3-792
3.7.19.2 T7351 Temper . . . . .	C3-801
3.7.19.3 T761 and T7651 Tempers . . . . .	C3-809
3.7.20 7065 ALLOY . . . . .	C3-817
3.7.20.0 Comments and Properties . . . . .	C3-817
3.7.20.1 T7451 Temper . . . . .	C3-822
3.7.20.2 T7651 Temper . . . . .	C3-829
3.8 200.0 SERIES CAST ALLOYS . . . . .	C3-837
3.8.1 A201.0 ALLOY . . . . .	C3-837
3.8.1.0 Comments and Properties. . . . .	C3-837
3.8.1.1 T7 Temper . . . . .	C3-840
3.8.2 205/TIB2/3P ALLOY . . . . .	C3-847
3.8.2.0 Comments and Properties. . . . .	C3-847
3.8.2.1 Investment Casting . . . . .	C3-849
3.8.2.2 Sand Casting . . . . .	C3-854
3.9 300.0 SERIES CAST ALLOYS . . . . .	C3-859
3.9.1 354.0 ALLOY . . . . .	C3-859
3.9.1.0 Comments and Properties. . . . .	C3-859
3.9.2 355.0 ALLOY . . . . .	C3-861
3.9.2.0 Comments and Properties. . . . .	C3-861
3.9.3 C355.0 ALLOY . . . . .	C3-864
3.9.3.0 Comments and Properties. . . . .	C3-864

# MMPDS-11 COMPLETE HANDBOOK

## PART 1 - Table of Contents

3.9.4 356.0 ALLOY . . . . .	C3-866
3.9.4.0 Comments and Properties. . . . .	C3-866
3.9.5 A356.0 ALLOY . . . . .	C3-869
3.9.5.0 Comments and Properties. . . . .	C3-869
3.9.5.1 T6 Temper . . . . .	C3-872
3.9.6 A357.0/F357.0 ALLOY . . . . .	C3-874
3.9.6.0 Comments and Properties. . . . .	C3-874
3.9.6.1 T6 Temper . . . . .	C3-877
3.9.7 D357.0/E357.0 ALLOY . . . . .	C3-878
3.9.7.0 Comments and Properties. . . . .	C3-878
3.9.7.1 T6 Temper . . . . .	C3-881
3.9.8 359.0 ALLOY . . . . .	C3-884
3.9.8.0 Comments and Properties. . . . .	C3-884
3.10 ELEMENT PROPERTIES . . . . .	C3-886
3.10.1 BEAMS. . . . .	C3-886
3.10.1.1 Simple Beams . . . . .	C3-886
3.10.1.2 Built-Up Beams. . . . .	C3-888
3.10.1.3 Thin-Web Beams . . . . .	C3-888
3.10.2 COLUMNS . . . . .	C3-889
3.10.2.1 Primary Failure . . . . .	C3-889
3.10.2.2 Local Failure. . . . .	C3-889
3.10.2.3 Column Properties . . . . .	C3-889
3.10.3 TORSION . . . . .	C3-891
3.10.3.1 General. . . . .	C3-891
3.10.3.2 Torsion Properties . . . . .	C3-891
REFERENCES . . . . .	REF-C3-1
11-APPENDICES . . . . .	A-1
11-Appendix A - Glossary . . . . .	A-1
A.1 Abbreviations . . . . .	A-1
A-2 Symbols . . . . .	A-5
A.3 Definitions . . . . .	A-6
A.4 Conversion of U.S. Units of Measure Used in MMPDS to SI Units . . . . .	A-17
11-Appendix B - Alloy Index . . . . .	B-1
11-Appendix C - Specification Index. . . . .	C-1
11-Appendix D - Testing Standards . . . . .	D-1
11-Appendix E - Subject Index . . . . .	E-1

# MMPDS-11 COMPLETE HANDBOOK

## PART 4 - Table of Contents

Foreword . . . . .	. i
Explanation of Numerical Code . . . . .	iii
Registered Trademarks . . . . .	v
CHAPTER 4 MAGNESIUM ALLOYS . . . . .	C4-1
4.1 GENERAL . . . . .	C4-1
4.1.1 ALLOY INDEX . . . . .	C4-1
4.1.2 MATERIAL PROPERTIES . . . . .	C4-1
4.1.2.1 Mechanical Properties . . . . .	C4-1
4.1.3 PHYSICAL PROPERTIES . . . . .	C4-4
4.1.4 ENVIRONMENTAL CONSIDERATIONS . . . . .	C4-4
4.1.5 ALLOY AND TEMPER DESIGNATIONS . . . . .	C4-4
4.1.6 JOINING METHODS . . . . .	C4-6
4.1.7 OBSOLETE ALLOYS, TEMPERS, AND PRODUCT FORMS . . . . .	C4-6
4.2 MAGNESIUM-WROUGHT ALLOYS . . . . .	C4-9
4.2.1 AZ31B . . . . .	C4-9
4.2.1.0 Comments and Properties. . . . .	C4-9
4.2.1.1 AZ31B-O Temper . . . . .	C4-15
4.2.1.2 AZ31B-H24 Temper . . . . .	C4-16
4.2.1.3 AZ31B-H26 Temper . . . . .	C4-19
4.2.1.4 AZ31B-F Temper . . . . .	C4-19
4.2.2 AZ61A . . . . .	C4-21
4.2.2.0 Comments and Properties. . . . .	C4-21
4.2.3 WE43C (Elektron 43) . . . . .	C4-23
4.2.3.0 Comments and Properties. . . . .	C4-23
4.2.3.1 WE43C-T5 Temper . . . . .	C4-27
4.2.4 ZK60A . . . . .	C4-35
4.2.4.0 Comments and Properties. . . . .	C4-35
4.2.4.1 ZK60A-F Temper . . . . .	C4-35
4.2.4.2 ZK60A-T5 Temper . . . . .	C4-39
4.3 MAGNESIUM CAST ALLOYS. . . . .	C4-43
4.3.1 AM100A . . . . .	C4-43
4.3.1.0 Comments and Properties. . . . .	C4-43
4.3.2 AZ91C/AZ91E. . . . .	C4-45
4.3.2.0 Comments and Properties. . . . .	C4-45
4.3.2.1 T6 Temper . . . . .	C4-48
4.3.3 AZ92A . . . . .	C4-49
4.3.3.0 Comments and Properties. . . . .	C4-49
4.3.3.1 AZ92A-T6 Temper . . . . .	C4-52
4.3.4 EV31A (ELEKTRON 21) ALLOY . . . . .	C4-55
4.3.4.0 Comments and Properties. . . . .	C4-55

# MMPDS-11 COMPLETE HANDBOOK

## PART 4 - Table of Contents

4.3.4.1. T6 Temper . . . . .	.C4-57
4.3.5 EZ33A . . . . .	.C4-61
4.3.5.0 Comments and Properties. . . . .	.C4-61
4.3.5.1 EZ33A-T5 Temper . . . . .	.C4-64
4.3.6 QE22A . . . . .	.C4-66
4.3.6.0 Comments and Properties. . . . .	.C4-66
4.3.6.1 QE22A-T6 Temper . . . . .	.C4-68
4.3.7 ZE41A . . . . .	.C4-70
4.3.7.0 Comments and Properties. . . . .	.C4-70
4.3.7.1 T5 Temper . . . . .	.C4-73
4.4 ELEMENT PROPERTIES . . . . .	.C4-75
4.4.1 BEAMS . . . . .	.C4-75
4.4.1.1 Simple Beams. . . . .	.C4-75
4.4.1.2 Built-Up Beams . . . . .	.C4-75
4.4.1.3 Thin-Web Beams . . . . .	.C4-75
4.4.2 COLUMNS . . . . .	.C4-75
4.4.2.1 Primary Failure . . . . .	.C4-75
4.4.2.2 Local Failure . . . . .	.C4-76
4.4.2.3 Column Properties . . . . .	.C4-76
4.4.3 TORSION . . . . .	.C4-77
4.4.3.1 General . . . . .	.C4-77
4.4.3.2 Torsion Properties . . . . .	.C4-77
REFERENCES . . . . .	REF-C4-1
CHAPTER 5 TITANIUM . . . . .	C5-1
5.1 GENERAL . . . . .	C5-1
5.1.1 TITANIUM INDEX. . . . .	C5-1
5.1.2 MATERIAL PROPERTIES . . . . .	C5-1
5.1.2.1 Mechanical Properties . . . . .	C5-2
5.1.3 MANUFACTURING CONSIDERATIONS . . . . .	C5-4
5.1.4 ENVIRONMENTAL CONSIDERATIONS . . . . .	C5-4
5.1.5 OBSOLETE ALLOYS, TEMPERS, AND PRODUCT FORMS . . . . .	C5-5
5.2 UNALLOYED TITANIUM . . . . .	C5-7
5.2.1 COMMERCIAL PURE TITANIUM. . . . .	C5-7
5.2.1.0 Comments and Properties. . . . .	C5-7
5.2.1.1 Annealed Condition. . . . .	.C5-12
5.3 ALPHA AND NEAR-ALPHA TITANIUM ALLOYS . . . . .	.C5-17
5.3.1 TI-5AL-2.5SN . . . . .	.C5-17
5.3.1.0 Comments and Properties. . . . .	.C5-17
5.3.1.1 Annealed Condition. . . . .	.C5-23
5.3.2 TI-8AL-1MO-1V . . . . .	.C5-32
5.3.2.0 Comments and Properties. . . . .	.C5-32
5.3.2.1 Single-Annealed Condition . . . . .	.C5-37

# MMPDS-11 COMPLETE HANDBOOK

## PART 4 - Table of Contents

5.3.2.2 Duplex-Annealed Condition . . . . .	C5-40
5.3.3 Ti-6Al-2Sn-4Zr-2Mo . . . . .	C5-48
5.3.3.0 Comments and Properties. . . . .	C5-48
5.3.3.1 Single, Duplex, and Triplex Annealed . . . . .	C5-53
5.4 ALPHA-BETA TITANIUM ALLOYS . . . . .	C5-57
5.4.1 TI-6AL-4V . . . . .	C5-57
5.4.1.0 Comments and Properties. . . . .	C5-57
5.4.1.1 Annealed Condition. . . . .	C5-71
5.4.1.2 Solution-Treated and Aged Condition . . . . .	C5-104
5.4.2 TI-6AL-6V-2SN . . . . .	C5-122
5.4.2.0 Comments and Properties. . . . .	C5-122
5.4.2.1 Annealed Condition. . . . .	C5-128
5.4.2.2 Solution-Treated and Aged Condition . . . . .	C5-138
5.4.3 TI-4.5AL-3V-2FE-2MO . . . . .	C5-139
5.4.3.0 Comments and Properties. . . . .	C5-139
5.4.3.1 Annealed Condition. . . . .	C5-139
5.4.4 TI-4AL-2.5V-1.5FE . . . . .	C5-148
5.4.4.0 Comments and Properties. . . . .	C5-148
5.4.4.1 Cold Rolled Sheet, Annealed Condition. . . . .	C5-154
5.4.4.2 Hot Rolled Sheet and Plate, Annealed Condition . . . . .	C5-162
5.5 BETA, NEAR-BETA, AND METASTABLE-BETA TITANIUM ALLOYS . . . . .	C5-171
5.5.1 TI-13V-11CR-3AL . . . . .	C5-171
5.5.1.0 Comments and Properties. . . . .	C5-171
5.5.1.1 Annealed Condition. . . . .	C5-175
5.5.1.2 Solution-Treated and Aged Condition . . . . .	C5-182
5.5.2 TI-15V-3CR-3SN-3AL (TI-15-3) . . . . .	C5-188
5.5.2.0 Comments . . . . .	C5-188
5.5.2.1 Solution-Treated and Aged (1000°F) Condition . . . . .	C5-191
5.5.3 TI-10V-2FE-3AL (TI-10-2-3) . . . . .	C5-192
5.5.3.0 Comments and Properties. . . . .	C5-192
5.5.3.1 Solution Treated and Aged (900° to 950°F) Condition. . . . .	C5-195
5.5.3.2 Solution Treated and Aged (950° to 1000°F) Condition . . . . .	C5-196
5.6 ELEMENT PROPERTIES . . . . .	C5-197
5.6.1 BEAMS . . . . .	C5-197
5.6.1.1 Simple Beams. . . . .	C5-197
REFERENCES . . . . .	REF-C5-1
CHAPTER 6 HEAT-RESISTANT ALLOYS . . . . .	C6-1
6.1 GENERAL . . . . .	C6-1
6.1.1 MATERIAL PROPERTIES . . . . .	C6-1
6.1.1.1 Mechanical Properties . . . . .	C6-1
6.1.1.2 Physical Properties . . . . .	C6-3
6.1.2 OBSOLETE ALLOYS, TEMPERS, AND PRODUCT FORMS . . . . .	C6-3

# MMPDS-11 COMPLETE HANDBOOK

## PART'4 - Table of Contents

6.2 IRON-CHROMIUM- NICKEL-BASE ALLOYS . . . . .	C6-5
6.2.0 GENERAL COMMENTS . . . . .	C6-5
6.2.0.1 Metallurgical Considerations . . . . .	C6-5
6.2.0.2 Manufacturing Considerations . . . . .	C6-5
6.2.1 A-286 . . . . .	C6-5
6.2.1.0 Comments and Properties . . . . .	C6-5
6.2.1.1 Solution-Treated and Aged Condition . . . . .	C6-8
6.2.2 N-155 . . . . .	C6-16
6.2.2.0 Comments and Properties . . . . .	C6-16
6.2.2.1 Solution-Treated Condition . . . . .	C6-18
6.3 NICKEL-BASE ALLOYS . . . . .	C6-21
6.3.0 GENERAL COMMENTS . . . . .	C6-21
6.3.0.1 Metallurgical Considerations . . . . .	C6-21
6.3.0.2 Manufacturing Considerations . . . . .	C6-21
6.3.1 HASTELLOY X . . . . .	C6-23
6.3.1.0 Comments and Properties . . . . .	C6-23
6.3.1.1 Solution Treated Condition . . . . .	C6-26
6.3.2 INCONEL 600 . . . . .	C6-29
6.3.2.0 Comments and Properties . . . . .	C6-29
6.3.2.1 Annealed Condition . . . . .	C6-34
6.3.3 INCONEL 625 . . . . .	C6-36
6.3.3.0 Comments and Properties . . . . .	C6-36
6.3.3.1 Annealed Condition . . . . .	C6-39
6.3.4 INCONEL 706 . . . . .	C6-47
6.3.4.0 Comments and Properties . . . . .	C6-47
6.3.4.1 Solution-Treated and Aged Condition (Creep Rupture Heat Treatment) . . . . .	C6-50
6.3.5 718 ALLOY . . . . .	C6-54
6.3.5.0 Comments and Properties . . . . .	C6-54
6.3.5.1 Solution-Treated and Aged Condition . . . . .	C6-61
6.3.6 INCONEL X-750 . . . . .	C6-95
6.3.6.0 Comments and Properties . . . . .	C6-95
6.3.6.1 Annealed and Aged . . . . .	C6-97
6.3.6.2 Equalized and Aged . . . . .	C6-99
6.3.7 RENÉ 41 . . . . .	C6-101
6.3.7.0 Comments and Properties . . . . .	C6-101
6.3.7.1 Solution Treated at 1975°F and Aged at 1400°F Condition . . . . .	C6-104
6.3.8 WASPALOY . . . . .	C6-124
6.3.8.0 Comments and Properties . . . . .	C6-124
6.3.8.1 Aged Condition . . . . .	C6-126
6.3.9. 230 ALLOY . . . . .	C6-130
6.3.9.0. Comments and Properties . . . . .	C6-130

# MMPDS-11 COMPLETE HANDBOOK

## PART 4 - Table of Contents

6.3.9.1. Annealed Condition . . . . .	C6-134
6.3.10 HR-120 ALLOY. . . . .	C6-143
6.3.10.0 Comments and Properties . . . . .	C6-143
6.3.10.1 Annealed Condition . . . . .	C6-143
6.3.11 HAYNES 282 ALLOY . . . . .	C6-149
6.3.11.0 Comments and Properties . . . . .	C6-149
6.3.11.1 Precipitation Hardened Condition . . . . .	C6-151
6.4 COBALT-BASE ALLOYS . . . . .	C6-163
6.4.0 GENERAL COMMENTS. . . . .	C6-163
6.4.0.1 Metallurgical Considerations . . . . .	C6-163
6.4.0.2 Manufacturing Considerations . . . . .	C6-163
6.4.0.3 Special Precautions . . . . .	C6-163
6.4.1 L-605 (25 alloy) . . . . .	C6-164
6.4.1.0 Comments and Properties. . . . .	C6-164
6.4.1.1 Solution Treated Condition . . . . .	C6-167
6.4.2 188 ALLOY. . . . .	C6-187
6.4.2.0 Comments and Properties. . . . .	C6-187
6.4.2.1 Solution-Treated Condition . . . . .	C6-189
REFERENCES . . . . .	REF-C6-1
CHAPTER 7 MISCELLANEOUS ALLOYS AND HYBRID MATERIALS . . . . .	C7-1
7.1 GENERAL . . . . .	C7-1
7.1.1 OBSOLETE ALLOYS, TEMPERS, AND PRODUCT FORMS . . . . .	C7-1
7.2 BERYLLIUM . . . . .	C7-3
7.2.0 GENERAL . . . . .	C7-3
7.2.1 STANDARD GRADE BERYLLIUM . . . . .	C7-3
7.2.1.0 Comments and Properties . . . . .	C7-3
7.2.1.0.1 Manufacturing Considerations. . . . .	C7-3
7.2.1.1 Hot-Pressed Condition . . . . .	C7-8
7.2.1.2 HIP'd Condition . . . . .	C7-12
7.3 COPPER AND COPPER ALLOYS . . . . .	C7-13
7.3.0 GENERAL . . . . .	C7-13
7.3.1 MANGANESE BRONZES . . . . .	C7-14
7.3.1.0 Comments and Properties . . . . .	C7-14
7.3.2 COPPER BERYLLIUM . . . . .	C7-17
7.3.2.0 Comments and Properties . . . . .	C7-17
7.3.2.1 TF00 Temper . . . . .	C7-24
7.3.2.2 TH04 Temper . . . . .	C7-25
7.3.3 COPPER-NICKEL-TIN (SPINODAL ALLOY). . . . .	C7-26
7.3.3.0 Comments and Properties . . . . .	C7-26
7.3.3.1 TX00 Temper . . . . .	C7-29
7.3.3.2 TX TS Temper . . . . .	C7-31
7.3.4 ALUMINUM BRONZES. . . . .	C7-34

# MMPDS-11 COMPLETE HANDBOOK

## PART 4 - Table of Contents

7.3.4.0 Comments and Properties . . . . .	.C7-34
7.4 MULTIPHASE ALLOYS . . . . .	.C7-37
7.4.0 GENERAL . . . . .	.C7-37
7.4.1 MP35N ALLOY . . . . .	.C7-37
7.4.1.0 Comments and Properties . . . . .	.C7-37
7.4.1.1 Cold Worked and Aged Condition . . . . .	.C7-39
7.4.2 MP159 ALLOY . . . . .	.C7-42
7.4.2.0 Comments and Properties . . . . .	.C7-42
7.4.2.1 Cold Worked and Aged Condition . . . . .	.C7-44
7.5 ALUMINUM ALLOY SHEET LAMINATES . . . . .	.C7-47
7.5.0 GENERAL . . . . .	.C7-47
7.5.1 2024-T3 ARAMID FIBER REINFORCED SHEET LAMINATE . . . . .	.C7-47
7.5.1.0 Comments and Properties . . . . .	.C7-47
7.5.1.1 T3 Temper . . . . .	.C7-49
7.5.2 7475-T761 ARAMID FIBER REINFORCED SHEET LAMINATE . . . . .	.C7-57
7.5.2.0 Comments and Properties . . . . .	.C7-57
7.5.2.1 T761 Temper . . . . .	.C7-59
7.6 ALUMINUM-BERYLLIUM HYBRIDS . . . . .	.C7-67
7.6.0 GENERAL . . . . .	.C7-67
7.6.1 AL-62BE . . . . .	.C7-67
7.6.1.0 Comments and Properties . . . . .	.C7-67
7.6.1.0.1 Manufacturing Considerations . . . . .	.C7-67
7.6.1.1 Hot Isostatic Pressed Condition . . . . .	.C7-69
REFERENCES . . . . .	REF-C7-1
CHAPTER 8 STRUCTURAL JOINTS . . . . .	C8-1
8.1 MECHANICALLY FASTENED JOINTS . . . . .	C8-3
8.1.1 INTRODUCTION AND FASTENER INDEXES . . . . .	C8-3
8.1.1.1 Data Sources . . . . .	.C8-13
8.1.1.2 Fastener Shear Strengths . . . . .	.C8-13
8.1.1.3 Edge Distance Requirements . . . . .	.C8-13
8.1.2 SOLID RIVETS . . . . .	.C8-15
8.1.2.1 Protruding-Head Solid Rivet Joints . . . . .	.C8-15
8.1.2.2 Flush-Head Solid Rivet Joints . . . . .	.C8-15
8.1.3 BLIND FASTENERS . . . . .	.C8-24
8.1.3.1 Protruding-Head Blind Fasteners . . . . .	.C8-24
8.1.3.2 Flush-Head Blind Fasteners . . . . .	.C8-24
8.1.4 SWAGED COLLAR/UPSET-PIN FASTENERS . . . . .	.C8-65
8.1.4.1 Protruding-Head Swaged Collar Fastener Joints . . . . .	.C8-65
8.1.4.2 Flush-Head Swaged Collar Fastener Joints . . . . .	.C8-66
8.1.5. THREADED FASTENERS . . . . .	.C8-76
8.1.5.1 Protruding-Head Threaded Fastener Joints . . . . .	.C8-76
8.1.5.2 Flush-Head Threaded Fastener Joints . . . . .	.C8-77

# MMPDS-11 COMPLETE HANDBOOK

## PART 4 - Table of Contents

- 8.1.6 SPECIAL FASTENERS . . . . . C8-83
  - 8.1.6.1 Fastener Sleeves . . . . . C8-83
  - 8.1.6.2 Sleeve Bolts . . . . . C8-83
- 8.1.7. Historical - Non-Confirmed Sunset Fastener Tables . . . . . C8-86
- 8.2 METALLURGICAL JOINTS. . . . . C8-99
  - 8.2.1 INTRODUCTION AND DEFINITIONS . . . . . C8-99
  - 8.2.2 WELDED JOINTS . . . . . C8-99
    - 8.2.2.1 Fusion Welding—Arc and Gas . . . . . C8-100
    - 8.2.2.2 Flash and Pressure Welding . . . . . C8-101
    - 8.2.2.3 Spot and Seam Welding . . . . . C8-101
- 8.3 BEARINGS, PULLEYS, AND WIRE ROPE . . . . . C8-121
- REFERENCES . . . . . REF-C8-1
- CHAPTER 9 GUIDELINES FOR THE PRESENTATION OF DATA . . . . . C9-1
  - 9.1 GENERAL INFORMATION . . . . . C9-1
    - 9.1.1 INTRODUCTION . . . . . C9-1
    - 9.1.2 CROSS INDEX . . . . . C9-1
    - 9.1.3 APPLICABILITY . . . . . C9-1
    - 9.1.4 APPROVAL PROCEDURES . . . . . C9-1
    - 9.1.5 DOCUMENTATION REQUIREMENTS . . . . . C9-1
    - 9.1.6 SUMMARY . . . . . C9-4
    - 9.1.7 DATA BASIS . . . . . C9-6
      - 9.1.7.1 Data Basis for Mechanical Properties (Chapters 2-7) . . . . . C9-6
      - 9.1.7.2 Data Basis for Mechanically Fastened Joint Allowables (Chapters 8) . . . . . C9-8
    - 9.1.8 ROUNDING PROCEDURES . . . . . C9-9
    - 9.1.9 APPLICABLE ANALYSISMETHODS . . . . . C9-9
  - 9.2 MATERIAL, SPECIFICATION, TESTING, AND DATA REQUIREMENTS . . . . . C9-11
    - 9.2.1 MATERIAL REQUIREMENTS . . . . . C9-11
    - 9.2.2 SPECIFICATION REQUIREMENTS . . . . . C9-11
      - 9.2.2.1 Requirements for Products Controlled by Material Specifications Not Listed in 9.2.2 . . . . . C9-11
    - 9.2.3 REQUIRED TEST METHODS/PROCEDURES. . . . . C9-12
      - 9.2.3.1 Mechanical- Property Terms. . . . . C9-15
      - 9.2.3.2 Testing Direction and Specimen Location . . . . . C9-15
      - 9.2.3.3 Tension, Compression, Shear and Bearing . . . . . C9-17
      - 9.2.3.4 Other Static Properties . . . . . C9-17
      - 9.2.3.5 Required Test Methods to Determine Dynamic and Time Dependent Properties . . . . . C9-18
      - 9.2.3.6 Mechanically Fastened Joints . . . . . C9-24
      - 9.2.3.7 Fusion-Welded Joints . . . . . C9-25
    - 9.2.4 DATA REQUIREMENTS . . . . . C9-26
      - 9.2.4.1 S-Basis Values . . . . . C9-26
      - 9.2.4.2 A- and B-Basis Values. . . . . C9-27

# MMPDS-11 COMPLETE HANDBOOK

## PART 4 - Table of Contents

9.2.4.3 Derived Property Values . . . . .	C9-32
9.2.4.4 Other Static Properties . . . . .	C9-33
9.2.4.5 Data Requirements for Determination of Dynamic and Time Dependent Properties . . . . .	C9-37
9.2.4.6 Mechanically Fastened Joints . . . . .	C9-41
9.2.4.7 Fastener Strength Table Sunset Clause . . . . .	C9-45
9.2.4.8 Fusion-Welded Joints . . . . .	C9-51
9.2.5 EXPERIMENTAL DESIGN . . . . .	C9-51
9.2.5.1 Uniformity of Sample Size across Thickness Range . . . . .	C9-51
9.2.5.2 Fatigue . . . . .	C9-52
9.2.5.3 Creep-Rupture. . . . .	C9-58
9.2.5.4 Fusion-Welded Joints . . . . .	C9-60
9.3 SUBMISSION OF DATA . . . . .	C9-63
9.3.1 RECOMMENDED PROCEDURES . . . . .	C9-63
9.3.2 COMPUTER SOFTWARE . . . . .	C9-63
9.3.3 INTRODUCTORY SECTION . . . . .	C9-63
9.3.4 GENERAL DATA FORMATS . . . . .	C9-63
9.3.4.1 Data Format for the Computation of T99 and T90 Values . . . . .	C9-64
9.3.4.2 Data Format for Derived Properties . . . . .	C9-64
9.3.4.3 Data Format for the Construction of Typical Stress-Strain Curves . . . . .	C9-68
9.3.4.4 Data Format for Fasteners . . . . .	C9-68
9.3.4.5 Data Format for Other Properties . . . . .	C9-69
9.4 SUBSTANTIATION OF PROPERTIES . . . . .	C9-73
9.4.1 S-BASIS MINIMUM PROPERTIES . . . . .	C9-73
9.4.2 VALIDATING DESIGN PROPERTIES FOR EXISTING MATERIALS (WHEN A CHANGE IN PROCESSING HAS OCCURRED) . . . . .	C9-74
9.4.3 CONFIRMATION OF DESIGN PROPERTIES FOR LEGACY ALLOYS . . . . .	C9-76
9.4.3.1 Initial Steps and Analysis. . . . .	C9-76
9.4.3.2 Increase in Design Properties . . . . .	C9-77
9.4.3.3 Decrease in Design Properties . . . . .	C9-77
9.4.3.4 Derived Properties . . . . .	C9-78
9.5 ANALYSIS PROCEDURES FOR STATISTICALLY COMPUTED MINIMUM STATIC PROPERTIES . . . . .	C9-83
9.5.1 SPECIFYING THE POPULATION . . . . .	C9-83
9.5.1.1 Deciding Between Direct and Indirect Computation . . . . .	C9-83
9.5.1.2 Testing for Regression Effects and Homogeneity . . . . .	C9-86
9.5.1.3 Data Transformation . . . . .	C9-90
9.5.2 REGRESSION ANALYSIS . . . . .	C9-98
9.5.2.1 Linear Regression . . . . .	C9-98
9.5.2.2 Quadratic Regression . . . . .	C9-100
9.5.2.3 Tests for Adequacy of a Regression . . . . .	C9-103
9.5.2.4 Testing for Equality of Several Regressions . . . . .	C9-105

# MMPDS-11 COMPLETE HANDBOOK

## PART 4 - Table of Contents

9.5.3 COMBINABILITY OF DATA . . . . .	C9-108
9.5.3.1 The k-Sample Anderson-Darling Test . . . . .	C9-108
9.5.3.2 The F Test . . . . .	C9-110
9.5.3.3 The t Test . . . . .	C9-111
9.5.4 DETERMINING THE FORM OF DISTRIBUTION . . . . .	C9-113
9.5.4.1 “Anderson-Darling” Test for Normality . . . . .	C9-113
9.5.4.2 Normal Probability Plot . . . . .	C9-114
9.5.4.3 Three-Parameter Weibull Acceptability Test . . . . .	C9-114
9.5.4.4 Modified Anderson-Darling Test for Pearsonality . . . . .	C9-116
9.5.4.5 The Pearson Backoff Option . . . . .	C9-117
9.5.4.6 Pearson Probability Plot . . . . .	C9-117
9.5.4.7 Modified “Anderson-Darling” Test for Weibullness . . . . .	C9-120
9.5.4.8 The Weibull Backoff Option . . . . .	C9-122
9.5.4.9 Weibull Probability Plots . . . . .	C9-123
9.5.4.10 Detection of Lower-Tail Truncation . . . . .	C9-125
9.5.5 DIRECT COMPUTATION WITHOUT REGRESSION . . . . .	C9-127
9.5.5.1 Sequential Pearson Procedure . . . . .	C9-132
9.5.5.2. Sequential Weibull Procedure . . . . .	C9-133
9.5.5.3 Nonparametric Procedure . . . . .	C9-134
9.5.5.4 Censored Normal Procedure . . . . .	C9-135
9.5.6 DIRECT COMPUTATION BY REGRESSION ANALYSIS . . . . .	C9-136
9.5.6.1 Performing the Regression . . . . .	C9-136
9.5.7 INDIRECT COMPUTATION WITHOUT REGRESSION (REDUCED RATIOS/ DERIVED PROPERTIES . . . . .	C9-137
9.5.7.1 Treatment of Grain Direction . . . . .	C9-138
9.5.7.2 Treatment of Test Specimen Location . . . . .	C9-139
9.5.7.3 Treatment of Clad Aluminum Alloy Plate . . . . .	C9-139
9.5.7.4 Computational Procedure . . . . .	C9-140
9.5.8 INDIRECT COMPUTATION USING REGRESSION . . . . .	C9-141
9.5.9 HANDLING OF DERIVED PROPERTY TEST RESULTS BELOW ESTIMATED DESIGN ALLOWABLE . . . . .	C9-142
9.5.10 INDIRECT COMPUTATION OF EDGEWISE BEARING REDUCTIONS . . . . .	C9-144
9.6 ANALYSIS PROCEDURES FOR DYNAMIC AND TIME DEPENDENT PROPERTIES . . . . .	C9-145
9.6.1 LOAD AND STRAIN CONTROL FATIGUE DATA . . . . .	C9-145
9.6.1.1 Data Collection and Interpretation . . . . .	C9-148
9.6.1.2 Analysis of Data . . . . .	C9-149
9.6.1.3 Fatigue Life Models . . . . .	C9-150
9.6.1.4 Evaluation of Mean Stress and Strain Effects . . . . .	C9-152
9.6.1.5 Estimation of Fatigue-Life Model Parameters . . . . .	C9-153
9.6.1.6 Treatment of Outliers . . . . .	C9-159
9.6.1.7 Assessment of the Fatigue Life Model . . . . .	C9-160
9.6.1.8 Data Set Combination . . . . .	C9-162
9.6.1.9 Treatment of Runouts . . . . .	C9-163

# MMPDS-11 COMPLETE HANDBOOK

## PART 4 - Table of Contents

9.6.1.10 Recognition of Time Dependent Effects . . . . .	C9-164
9.6.1.11 Estimation of Lower Tolerance Bounds for Fatigue Data . . . . .	C9-165
9.6.2 FATIGUE CRACK GROWTH DATA . . . . .	C9-166
9.6.2.1 Data Collection and Interpretation. . . . .	C9-167
9.6.3 FRACTURE TOUGHNESS DATA . . . . .	C9-169
9.6.3.1 Plane-Strain Fracture Toughness Data . . . . .	C9-169
9.6.3.2 Plane Stress and Transitional Fracture Toughness . . . . .	C9-170
9.6.3.3 Crack Resistance (R-Curve) . . . . .	C9-171
9.6.4 CREEP AND CREEP-RUPTURE DATA . . . . .	C9-177
9.6.4.1 Data Collection and Interpretation. . . . .	C9-177
9.6.4.2 Analysis of Data . . . . .	C9-179
9.7 ANALYSIS PROCEDURES FOR STRUCTURAL JOINT PROPERTIES. . . . .	C9-183
9.7.1 MECHANICALLY FASTENED JOINTS . . . . .	C9-183
9.7.1.1 Definitions . . . . .	C9-184
9.7.1.2 Yield Load Determination . . . . .	C9-185
9.7.1.3 Shear Strength of Fastener . . . . .	C9-190
9.7.1.4 Sheet Critical and Transition Critical Strengths . . . . .	C9-193
9.7.1.5 Calculation of Allowable Loads . . . . .	C9-212
9.7.2 FUSION-WELDED JOINT DATA . . . . .	C9-213
9.7.2.1 Data Collection and Interpretation. . . . .	C9-214
9.7.2.2 Data Analysis . . . . .	C9-216
9.8 EXAMPLES OF DATA ANALYSIS AND DATA PRESENTATION FOR STATIC PROPERTIES . . . . .	C9-217
9.8.1 DIRECT ANALYSES OF MECHANICAL PROPERTIES . . . . .	C9-217
9.8.2 INDIRECT ANALYSES OF MECHANICAL PROPERTIES . . . . .	C9-230
9.8.3 TABULAR DATA PRESENTATION . . . . .	C9-234
9.8.3.1 Mechanical Properties . . . . .	C9-234
9.8.3.2 Modulus of Elasticity and Poisson's Ratio . . . . .	C9-239
9.8.3.3 Physical Properties . . . . .	C9-240
9.8.4 ROOM TEMPERATURE GRAPHICAL MECHANICAL PROPERTY DATA. . . . .	C9-240
9.8.4.1 Typical Stress-Strain . . . . .	C9-240
9.8.4.2 Compression-Tangent-Modulus Curves. . . . .	C9-252
9.8.4.3 Full Range Tensile Stress-Strain Curves . . . . .	C9-258
9.8.4.4 Minimum Stress-Strain and Stress Tangent-Modulus Curves . . . . .	C9-264
9.8.4.5 Biaxial Stress-Strain Behavior . . . . .	C9-264
9.8.4.6 Mathematical Representation of Stress-Strain Curves . . . . .	C9-264
9.8.5 ELEVATED TEMPERATURE GRAPHICAL MECHANICAL PROPERTIES. . . . .	C9-267
9.8.5.1 Strength Properties . . . . .	C9-267
9.8.5.2 Elongation and Reduction of Area. . . . .	C9-278
9.8.5.3 Modulus of Elasticity . . . . .	C9-278
9.8.5.4 Physical Properties . . . . .	C9-279
9.8.5.5 Effect of Thermal Exposure on Room Temperature Strength . . . . .	C9-281

# MMPDS-11 COMPLETE HANDBOOK

## PART 4 - Table of Contents

9.8.5.6 Effect of Thermal Exposure on Elevated Temperature Strength . . . . .	C9-282
9.8.5.7 Simple Exposure . . . . .	C9-282
9.8.5.8 Complex Exposure . . . . .	C9-283
9.9 EXAMPLES OF DATA FOR DYNAMIC AND TIME DEPENDANT PROPERTIES . . . . .	C9-287
9.9.1 FATIGUE . . . . .	C9-287
9.9.1.1 Load Control . . . . .	C9-294
9.9.1.2 Strain Control . . . . .	C9-301
9.9.2 FATIGUE CRACK GROWTH . . . . .	C9-304
9.9.3 FRACTURE TOUGHNESS . . . . .	C9-310
9.9.3.1 Plane Strain . . . . .	C9-310
9.9.3.2 Plane Stress . . . . .	C9-310
9.9.4 CREEP AND CREEP RUPTURE . . . . .	C9-311
9.9.4.1 Creep-Rupture Example Problem . . . . .	C9-312
9.9.5 MECHANICALLY FASTENED JOINTS . . . . .	C9-318
9.9.5.1 Example Analysis Problem for Three Diameter Blind Fastener Dataset . . . . .	C9-324
9.9.6 FUSION - WELDED JOINTS . . . . .	C9-361
9.9.6.1 Additional Information . . . . .	C9-361
9.9.6.2 Room-Temperature Properties . . . . .	C9-361
9.9.6.3 Data on Effect of Temperature . . . . .	C9-362
9.9.6.4 Use of Design Data . . . . .	C9-363
9.10 STATISTICAL TABLES . . . . .	C9-365
REFERENCES . . . . .	REF-C9-1
11-APPENDICES . . . . .	A-1
11-Appendix A - Glossary . . . . .	A-1
A.1 Abbreviations . . . . .	A-1
A.2 Symbols . . . . .	A-5
A.3 Definitions . . . . .	A-5
A.4 Conversion of U.S. Units of Measure Used in MMPDS to SI Units . . . . .	A-17
11-Appendix B - Alloy Index . . . . .	B-1
11-Appendix C - Specification Index . . . . .	C-1
11-Appendix D - Testing Standards . . . . .	D-1
11-Appendix E - Subject Index . . . . .	E-1