



BSI Standards Publication

Space engineering — Structural materials handbook

Part 5: New advanced materials, advanced metallic materials, general design aspects and load transfer and design of joints

National foreword

This Published Document is the UK implementation of CEN/TR 17603-32-05:2022.

The UK participation in its preparation was entrusted to Technical Committee ACE/68, Space systems and operations.

A list of organizations represented on this committee can be obtained on request to its committee manager.

Contractual and legal considerations

This publication has been prepared in good faith, however no representation, warranty, assurance or undertaking (express or implied) is or will be made, and no responsibility or liability is or will be accepted by BSI in relation to the adequacy, accuracy, completeness or reasonableness of this publication. All and any such responsibility and liability is expressly disclaimed to the full extent permitted by the law.

This publication is provided as is, and is to be used at the recipient's own risk.

The recipient is advised to consider seeking professional guidance with respect to its use of this publication.

This publication is not intended to constitute a contract. Users are responsible for its correct application.

© The British Standards Institution 2022
Published by BSI Standards Limited 2022

ISBN 978 0 539 127 8 0

ICS 49.140

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 March 2022.

Amendments/corrigenda issued since publication

Date	Text affected
------	---------------

TECHNICAL REPORT

CEN/TR 17603-32-05

RAPPORT TECHNIQUE

TECHNISCHER BERICHT

January 2022

ICS 49.140

English version

Space engineering - Structural materials handbook - Part 5: New advanced materials, advanced metallic materials - general design aspects and load transfer and design of joints

Ingénierie spatiale - Manuel des matériaux structuraux
- Partie 5 : Matériaux avancés nouveaux, matériaux
métalliques avancés, aspects généraux de conception,
transferts des charges et conception des jonctions

Raumfahrttechnik - Handbuch der
Konstruktionswerkstoffe - Teil 5: Neue fortschrittliche
Werkstoffe, fortschrittliche metallische Werkstoffe,
allgemeine Konstruktionsaspekte und Lastabtragung
und Auslegung von Verbindungen

This Technical Report was approved by CEN on 29 November 2021. It has been drawn up by the Technical Committee CEN/CLC/JTC 5.

CEN and CENELEC members are the national standards bodies and national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.



**CEN-CENELEC Management Centre:
Rue de la Science 23, B-1040 Brussels**

Table of contents

European Foreword	25
Introduction	26
46 Aluminium alloys and their composites	27
46.1 Introduction.....	27
46.1.1 General.....	27
46.1.2 Conventional aluminium alloys.....	27
46.1.3 New aluminium alloys	27
46.1.4 MMC - metal matrix composites.....	28
46.1.5 FML - fibre metal laminates.....	28
46.1.6 Material availability.....	28
46.2 Conventional aluminium alloys.....	29
46.2.1 General.....	29
46.2.2 Chemical composition.....	29
46.2.3 Aerospace alloys.....	35
46.2.4 Properties	35
46.3 New aluminium alloys.....	36
46.3.1 Developments.....	36
46.3.2 Aluminium-cadmium alloys.....	36
46.4 Al-Li - Aluminium-lithium alloys	37
46.4.1 Development.....	37
46.4.2 Processing	37
46.4.3 Applications.....	38
46.4.4 Producers	38
46.4.5 Manufacturing processes	40
46.5 Al-Li alloys: Characteristics.....	41
46.5.1 General.....	41
46.5.2 Microstructure	42
46.5.3 Further development.....	43
46.6 Al-Li alloys: Properties	43
46.6.1 Data.....	43

46.6.2	Tensile properties	43
46.6.3	Fracture properties.....	45
46.6.4	Fatigue properties	47
46.6.5	Design values	51
46.6.6	Further development alloys	52
46.7	Al-Li alloys: Stress corrosion cracking.....	52
46.7.1	General.....	52
46.7.2	Test.....	53
46.7.3	Stress corrosion cracking resistance.....	53
46.7.4	Recent alloys	53
46.8	Al-Li alloys: Manufacturing aspects.....	57
46.8.1	General.....	57
46.8.2	Machining	57
46.8.3	Welding.....	57
46.8.4	Cost implications.....	58
46.8.5	Applications.....	59
46.8.6	Mass-saving.....	59
46.9	Al-Li alloys: Potential applications.....	59
46.9.1	General factors	59
46.9.2	Space Shuttle external tank	60
46.9.3	A380 - Floor beams.....	62
46.10	Oxide dispersion strengthened (ODS) alloys	63
46.10.1	Type and effect of dispersions	63
46.10.2	Processing	63
46.10.3	Cost factors.....	64
46.10.4	Applications	64
46.10.5	Properties	65
46.11	Rapidly solidified powder (RSP) alloys.....	71
46.11.1	Processing	71
46.11.2	Microstructure	72
46.11.3	Development.....	72
46.11.4	Ambient temperature.....	72
46.11.5	Elevated temperature.....	74
46.12	Al-MMCs - Metal matrix composites	76
46.12.1	Introduction.....	76
46.12.2	Manufacturing processes	76
46.12.3	Reinforcement materials	77

46.12.4 MMC nomenclature.....	77
46.12.5 Advantages of MMC's	78
46.12.6 Material availability.....	78
46.12.7 Sources of further information	79
46.13 Discontinuously reinforced Al-MMCs	80
46.13.1 Features.....	80
46.13.2 Development.....	80
46.13.3 Matrix alloys	80
46.13.4 Types of reinforcement	80
46.13.5 Processing	83
46.14 Discontinuously reinforced Al-alloys: Properties	85
46.14.1 General.....	85
46.14.2 Powder metallurgy MMCs	86
46.14.3 MMC's produced by melt infiltration processes	92
46.14.4 Spray-formed materials.....	99
46.14.5 Further information.....	100
46.15 Continuously Reinforced Al-Alloy MMC	101
46.15.1 General.....	101
46.15.2 Fibres.....	101
46.15.3 Matrix alloys	104
46.15.4 Characteristics	104
46.15.5 Processing	105
46.16 Continuously reinforced Al-alloy MMC: Properties	106
46.16.1 Mechanical properties.....	106
46.16.2 Physical properties.....	111
46.17 Al-alloy MMC: Potential applications.....	111
46.17.1 Benefits of Aluminium-matrix composites.....	111
46.17.2 High specific strength and temperature resistance.....	112
46.17.3 High specific stiffness and good thermal properties.....	112
46.17.4 High conductivity with low thermal expansion.....	113
46.17.5 High specific stiffness and dimensional stability	113
46.17.6 High specific strength and chemical resistance	113
46.18 References	113
46.18.1 General.....	113
46.18.2 Sources.....	122
46.18.3 ECSS documents.....	123
46.18.4 ASTM standards	123

46.18.5 Other standards	123
47 Titanium alloys and their composites.....	125
47.1 Introduction.....	125
47.2 Conventional alloys.....	125
47.2.1 Material selection factors.....	125
47.2.2 Microstructure	126
47.2.3 Effect of alloy elements	126
47.2.4 Alloy classes	127
47.2.5 Alloys for aerospace use.....	128
47.2.6 Heat treatment	130
47.2.7 Mechanical properties	130
47.2.8 Physical properties.....	136
47.3 New alloys	137
47.3.1 Developments	137
47.3.2 Processing techniques.....	137
47.4 Superplastic forming and diffusion bonding	138
47.4.1 Superplasticity.....	138
47.4.2 Diffusion bonding	138
47.4.3 SPF/DB fabrication.....	138
47.4.4 Materials	139
47.5 Discontinuously reinforced Ti-alloys	140
47.5.1 Difficulties	140
47.5.2 Particulate reinforcements.....	140
47.5.3 Processing	141
47.5.4 Properties	141
47.5.5 Further development.....	141
47.6 Continuous fibre reinforced Ti-alloy MMC	141
47.6.1 Composite development	141
47.6.2 Monofilament reinforcements	142
47.6.3 Matrix selection	143
47.6.4 Composite process technologies.....	143
47.7 Continuous fibre reinforced Ti-alloy MMC: properties	144
47.7.1 Composite optimisation.....	144
47.7.2 Tensile strength and stiffness.....	144
47.7.3 Fatigue.....	146
47.7.4 Fracture toughness	147
47.7.5 Elevated temperatures	147

47.7.6	Thermo-mechanical fatigue	147
47.8	Titanium alloys: Effect of hydrogen	149
47.8.1	Material degradation mechanisms	149
47.9	Titanium alloys: Effect of oxygen	150
47.9.1	Oxidation	150
47.9.2	Ignition and burning	151
47.10	Coatings and protection systems	151
47.10.1	Requirements	151
47.10.2	Potential coatings	151
47.11	Ti-alloys and MMCs: Potential applications	152
47.11.1	Current use	152
47.11.2	Developments	152
47.11.3	Aerospace applications	153
47.12	References	154
47.12.1	General	154
47.12.2	ECSS documents	157
48	Superalloys and their composites	158
48.1	Introduction	158
48.1.1	General	158
48.1.2	Alloy development	158
48.1.3	Composites	158
48.1.4	Service environment	159
48.1.5	Coating systems	159
48.2	Conventional alloys	159
48.2.1	General	159
48.2.2	Alloy groups	159
48.2.3	Aircraft engine applications	160
48.2.4	Spacecraft engine applications	168
48.3	New alloys	171
48.3.1	Developments	171
48.3.2	Directional solidification (DS)	172
48.3.3	Single crystal (SC)	172
48.3.4	Powder metallurgy (PM)	173
48.3.5	Oxide dispersion strengthened (ODS) alloys	175
48.4	Discontinuously reinforced composites	177
48.5	Continuously reinforced composites	178
48.5.1	Composite development	178

48.6	Tungsten fibre reinforced superalloy (TFRS) composites.....	179
48.6.1	Development.....	179
48.6.2	Matrix alloys.....	180
48.6.3	Mechanical properties.....	180
48.6.4	Characteristics.....	186
48.7	Effect of hydrogen.....	186
48.7.1	Degradation mechanisms.....	186
48.7.2	Hydrogen embrittlement (HE).....	187
48.7.3	Hydrogen environment embrittlement (HEE).....	188
48.7.4	Material sensitivity.....	188
48.7.5	Creep in hydrogen environments.....	191
48.7.6	Fatigue in hydrogen environments.....	196
48.7.7	Fracture characteristics.....	197
48.8	Effect of oxygen.....	200
48.8.1	Material selection factors.....	200
48.8.2	Oxidation.....	200
48.8.3	Oxidation resistance.....	200
48.8.4	Ignition and burn.....	201
48.9	Coatings and protection systems.....	202
48.9.1	Requirements.....	202
48.9.2	Types of coatings.....	203
48.9.3	Coating systems.....	203
48.9.4	Coated components.....	203
48.9.5	Hydrogen fuel.....	203
48.10	Diffusion coatings.....	204
48.10.1	Types of coatings.....	204
48.11	Overlay coatings.....	207
48.11.1	Development.....	207
48.12	Thermal barrier coatings (TBC).....	209
48.12.1	Function.....	209
48.12.2	Coating construction.....	210
48.13	Coating influence on design.....	211
48.13.1	Factors.....	211
48.13.2	Effect of coatings on mechanical properties.....	213
48.13.3	Chemical interaction.....	214
48.13.4	Residual strains.....	215
48.13.5	Tensile behaviour.....	217

48.13.6	Fatigue resistance.....	218
48.13.7	Creep and relaxation.....	221
48.13.8	Creep fatigue	226
48.14	Coatings: Future developments	227
48.14.1	Materials	227
48.14.2	Service temperature.....	228
48.14.3	Hydrogen environments	228
48.15	Superalloys: Potential applications	228
48.15.1	Conventional alloys	228
48.16	References	230
48.16.1	General.....	230
48.16.2	ECSS documents.....	234
49	Intermetallic materials.....	235
49.1	Introduction.....	235
49.1.1	Types of intermetallic compounds	235
49.2	Aluminide development	235
49.2.1	Features.....	235
49.2.2	Applications.....	236
49.2.3	Property data	237
49.2.4	Availability.....	237
49.3	Nickel aluminides.....	237
49.3.1	Characteristics	237
49.4	Nickel aluminides: Properties	240
49.4.1	General.....	240
49.4.2	Mechanical properties	240
49.4.3	Oxidation resistance.....	243
49.4.4	Aqueous corrosion	243
49.4.5	Coefficient of thermal expansion (CTE).....	243
49.5	Titanium aluminides.....	244
49.5.1	General.....	244
49.5.2	Characteristics	244
49.5.3	Effect of micro-alloying or doping	245
49.6	Titanium aluminides: Properties.....	247
49.6.1	General.....	247
49.6.2	Mechanical properties	247
49.6.3	Oxidation resistance.....	255
49.6.4	Thermophysical properties	256

49.7	Iron aluminides	260
49.7.1	Characteristics	260
49.8	Processing.....	263
49.8.1	Development.....	263
49.8.2	Material processing	263
49.8.3	Joining	266
49.9	Further developments.....	266
49.9.1	Intermetallic compounds	266
49.9.2	Intermetallic matrix composites (IMC)	267
49.9.3	Protective coatings.....	268
49.10	Intermetallic matrix composites.....	268
49.10.1	General.....	268
49.10.2	Development.....	268
49.10.3	High temperature Ti-based IMC	270
49.11	Intermetallics: Potential applications	274
49.11.1	General.....	274
49.11.2	Spaceplanes	276
49.12	References	276
49.12.1	General.....	276
50	Refractory and precious metals	280
50.1	Introduction.....	280
50.2	Materials.....	280
50.2.1	General.....	280
50.2.2	Characteristics	280
50.2.3	Basic properties	281
50.2.4	Alloys	282
50.3	Applications	282
51	Beryllium	283
51.1	Introduction.....	283
51.2	Characteristics.....	283
51.2.1	Features.....	283
51.2.2	Applications.....	283
51.3	Products and facilities	284
51.3.1	Source	284
51.3.2	Materials	284
51.3.3	Grades.....	284
51.3.4	Fabrication	285

51.4	Properties	286
51.4.1	Influence of microstructure	286
51.4.2	Grades	286
51.4.3	Mechanical properties	287
51.4.4	Effect of temperature.....	287
51.5	Health and safety.....	294
51.5.1	Facilities	294
51.5.2	Health aspects	294
51.5.3	Extraction.....	295
51.6	Potential applications.....	295
51.6.1	Resumé	295
51.7	References	295
51.7.1	General.....	295
52	Ceramic matrix composites.....	296
52.1	Introduction.....	296
52.2	Continuous fibre composites.....	296
52.2.1	Matrix groups	296
52.2.2	Composite development	298
52.2.3	Technology status.....	301
52.2.4	Characteristics	301
52.3	Carbon fibre reinforced silicon carbide.....	302
52.3.1	General.....	302
52.3.2	Fibres.....	303
52.3.3	Matrix.....	303
52.3.4	Characteristics	304
52.3.5	C/SiC LPI liquid polymer infiltration process.....	306
52.3.6	C/C-SiC LSI liquid silicon infiltration process.....	314
52.4	Silicon carbide fibre reinforced silicon carbide	315
52.4.1	Technology status.....	315
52.4.2	Applications.....	316
52.4.3	Characteristics	316
52.4.4	Manufacturing of SiC-SiC.....	316
52.5	SiC-SiC composite: Properties.....	317
52.5.1	General.....	317
52.5.2	Mechanical properties	317
52.5.3	Environment.....	320
52.6	Whisker reinforced composites.....	321

52.6.1	Development.....	321
52.6.2	Properties	324
52.6.3	Applications.....	324
52.7	Potential applications.....	324
52.7.1	Resumé	324
52.7.2	High temperature applications.....	324
52.7.3	High precision optical structures.....	327
52.8	References	329
52.8.1	General.....	329
53	Glass and glass-ceramic matrix composites	337
53.1	Introduction.....	337
53.2	Continuous fibre composites.....	337
53.2.1	Characteristics	337
53.2.2	Composite development	338
53.2.3	Manufacture.....	339
53.3	Carbon fibre reinforced composites	340
53.3.1	Material	340
53.3.2	Mechanical properties	340
53.3.3	Applications.....	343
53.4	Silicon carbide fibre reinforced composites.....	344
53.4.1	Composite development	344
53.4.2	Effect of in-situ fibre strength.....	346
53.4.3	Effect of fibre-matrix bonding	346
53.5	Silicon carbide reinforced composites: properties	346
53.5.1	LAS matrix composites	346
53.5.2	Mechanical properties	348
53.6	Potential applications.....	358
53.6.1	Technology status.....	358
53.7	References	359
53.7.1	General.....	359
54	Carbon-Carbon matrix composites.....	362
54.1	Introduction.....	362
54.1.1	Applications.....	362
54.1.2	High temperature	362
54.1.3	Dimensional stability	362
54.2	Material description.....	362
54.2.1	Characteristics	362

54.2.2	Manufacturing techniques	364
54.3	C-C composite: Properties	367
54.3.1	Mechanical properties	367
54.4	Oxidation protection systems	371
54.4.1	Requirements	371
54.4.2	Coating development	371
54.4.3	Matrix modification	371
54.4.4	Design factors	372
54.5	Potential applications	373
54.5.1	Resumé	373
54.5.2	Commercial availability	373
54.6	Dimensionally stable structures	374
54.6.1	Introduction	374
54.6.2	Material characterisation	375
54.6.3	Manufacturing process	375
54.6.4	Sandwich structures	377
54.6.5	Cylinder structures	378
54.7	References	380
54.7.1	General	380
55	Material availability	383
55.1	Introduction	383
55.2	Material forms	383
55.2.1	General	383
55.2.2	Procurement	383
55.2.3	Processing	383
55.3	Standard product forms	384
55.3.1	General	384
55.3.2	Wrought metal products	384
55.3.3	Standard materials for net-shape processing	384
55.4	Net-shape components	385
55.5	Data and product support	385
55.5.1	Material supply	385
55.5.2	Property data	386
55.6	Data sources	386
55.6.1	European expertise	386
55.7	Costs	388
55.7.1	Relative comparisons of materials	388

56	General design rules	391
56.1	Introduction.....	391
56.2	Mechanical response.....	391
56.2.1	General.....	391
56.2.2	Composite development	391
56.2.3	Material characteristics	392
56.3	Stress-strain response.....	394
56.3.1	Isotropic and anisotropic materials	394
56.4	Fracture characteristics	397
56.4.1	General.....	397
56.4.2	Near-isotropic materials with modest ductility.....	397
56.4.3	Anisotropic, fibre reinforced MMCs	397
56.4.4	Anisotropic, fibre reinforced CMCs.....	398
56.5	Residual stresses	399
56.5.1	Isotropic materials.....	399
56.5.2	Anisotropic materials.....	399
56.5.3	Influence on microstructure	399
56.5.4	Influence on structures.....	400
56.6	Defects.....	400
56.6.1	General.....	400
56.6.2	Defect sources	400
56.6.3	Isotropic materials.....	400
56.6.4	Anisotropic materials.....	401
56.7	Machining	402
56.7.1	General.....	402
56.7.2	Isotropic metal alloys.....	402
56.7.3	Particulate MMC	402
56.7.4	Continuous fibre MMC	402
56.7.5	Carbon-Carbon composites	403
56.7.6	Ceramic matrix composites	403
56.7.7	Techniques	403
57	Environmental aspects of design.....	404
57.1	Introduction.....	404
57.2	Space parameters	404
57.2.1	Material selection	404
57.3	Application specifics	405
57.3.1	Material selection	405

57.4	Protection systems	406
57.4.1	Requirements.....	406
57.4.2	Types of protection systems.....	406
57.4.3	Evaluation of protection systems.....	407
57.5	References	408
57.5.1	General.....	408
58	Joint selection factors.....	410
58.1	Introduction.....	410
58.2	Basic considerations.....	410
58.2.1	Material characteristics	410
58.2.2	Joint strength	413
58.2.3	Joint design factors	414
58.3	Interlayers.....	414
58.3.1	Function and effect on fused joints.....	414
58.4	Joint consolidation	415
58.4.1	Temperature and pressure.....	415
58.5	Material compatibility	416
58.5.1	Chemical and physical	416
58.6	Load introduction	417
58.6.1	Basic principles	417
58.7	Operational environment.....	418
58.7.1	Environmental factors	418
58.8	References	418
58.8.1	General.....	418
59	Joints between dissimilar materials	419
59.1	Introduction.....	419
59.2	Requirements	419
59.2.1	Temperature range	419
59.2.2	Structures	419
59.2.3	Loading.....	420
59.2.4	Joining methods.....	420
59.2.5	Joint components.....	421
60	Fusion joining.....	422
60.1	Introduction.....	422
60.2	Joining techniques.....	422
60.2.1	General.....	422

60.2.2	Liquid-phase processing	423
60.2.3	Solid-phase processing.....	424
60.3	Joint configuration and performance	424
60.3.1	Technology status	424
60.3.2	Joint strength	427
60.4	References	428
60.4.1	General.....	428
61	Mechanical connections	432
61.1	Introduction.....	432
61.1.1	Requirements.....	432
61.2	Versatile joints	433
61.2.1	Applications.....	433
61.2.2	Mechanical techniques.....	433
62	(Heading number reserved)	435
63	(Heading number reserved)	435

Figures

Figure 46.2-1	– Aluminium alloys: Chemical composition and temper designation	30
Figure 46.6-1	- Al-Li alloys: Fracture toughness versus yield strength for sheet materials	47
Figure 46.6-2	- Al-Li alloys: Comparison of fatigue crack growth behaviour for 2024-T3 and 8090-T81.....	48
Figure 46.6-3	- Al-Li alloys: Comparison of fatigue crack growth behaviour for 2024-T3 and 2091-T8X	49
Figure 46.6-4	- Al-Li alloys: Comparison of fatigue crack growth behaviour LITAL A (8090) forgings at 20°C	51
Figure 46.7-1	- Al-Li Alloys: Influence of temper on stress corrosion cracking initiation for 8090 plates, S-T direction	54
Figure 46.9-1	- Al-Li alloys: Applications - Space Shuttle external tank, major changes from LWT	61
Figure 46.9-2	- Al-Li alloys: Applications – Airbus A380 floor beams	63
Figure 46.10-1	- Aluminium ODS alloys: Comparison of elevated temperature tensile strength for various mechanically alloyed materials with Al-2618	65
Figure 46.10-2	- Aluminium ODS alloys: Comparison of elevated temperature tensile strength, proof stress and ductility	66
Figure 46.10-3	- Aluminium ODS alloys: Effect of consolidation method on proof stress	67
Figure 46.10-4	- Aluminium ODS alloys: Effect of consolidation method on ductility	68
Figure 46.10-5	- Aluminium ODS alloys: Creep response at 400°C for 3 stress levels	69

Figure 46.10-6 - Aluminium ODS alloys: Comparison of tensile creep curves at different stress levels with Al-2618	70
Figure 46.10-7 - Aluminium ODS alloys: Comparison of fatigue resistance with Al-2024.....	71
Figure 46.12-1 – Al-MMCs: Overview of manufacturing processes.....	77
Figure 46.14-1 – Al-MMCs: Typical elevated temperature properties of 2009/SiC-T4 DRA compared with conventional wrought aluminium alloys	91
Figure 46.14-2 – Al-MMCs: Typical room and elevated temperature fatigue properties of 2009/SiC DRA compared with conventional wrought aluminium alloys.....	92
Figure 46.17-1 – Al-MMCs: Comparison between Al-continuously reinforced alumina fibre composites and other materials	112
Figure 47.2-1 - Titanium alloys: Effect of temperature on stiffness	132
Figure 47.2-2 - Titanium alloys: Effect of temperature on strength.....	133
Figure 47.2-3 - Titanium alloys: Creep properties	134
Figure 47.2-4 - Titanium alloys: Fatigue strength.....	135
Figure 47.2-5 - Titanium alloys: UTS at elevated temperature for IMI 829 and Ti-1100	136
Figure 47.4-1 - SPF/DB fabrication: Titanium alloy <i>m</i> -values as a function of strain rate.....	140
Figure 47.7-1 - Titanium matrix composites: Fatigue life from in-phase and out-of-phase thermal-mechanical fatigue tests	149
Figure 48.2-1 - Superalloys: Development Curve	160
Figure 48.2-2 - Superalloys: Cooled turbine blade.....	168
Figure 48.2-3 - Operating regimes for Space Shuttle and aero-engine turbines	170
Figure 48.3-1 - ODS superalloys: Comparison of yield strength with casting superalloys.....	176
Figure 48.3-2 - ODS superalloys: Comparison of tensile elongation with casting superalloys.....	177
Figure 48.7-1 - Effect of hydrogen on creep rupture of Inconel 718 STA2	192
Figure 48.7-2 - Effect of hydrogen on creep rupture of Inconel 718 STA1	193
Figure 48.7-3 - Effect of hydrogen on creep rupture of Inconel 625	193
Figure 48.7-4 - Effect of hydrogen on creep rupture of Waspalloy	194
Figure 48.7-5 - Effect of hydrogen on creep rupture of MAR-M-246 conventionally cast.....	194
Figure 48.7-6 - Effect of hydrogen on creep rupture of MAR-M-246 directionally solidified	195
Figure 48.7-7 - Effect of hydrogen on creep rupture of MAR-M-246 single crystal	195
Figure 48.7-8 - Low cycle fatigue (LCF) life of Inconel 718 against temperature.....	196
Figure 48.7-9 - Superalloys: Crack growth rate of IN718 under various stress intensities and hydrogen environments	198
Figure 48.7-10 - Superalloys: Crack growth rate of IN718 as a function of cyclic rates and hydrogen environments.....	199
Figure 48.12-1 - Thermal barrier coating: Typical construction materials	210

Figure 48.13-1 - Coating design: Effect of temperature gradients on diffusion	215
Figure 48.13-2 - Coating design: Example of failure diagram for IN-738LC	219
Figure 48.13-3 - Coating design: High cycle fatigue characteristics of coated CMSX-2.....	221
Figure 48.13-4 - Coating design: Schematic creep curves for substrate metal and coating	222
Figure 48.13-5 - Coating design: Schematic creep curves for coated system.....	222
Figure 48.13-6 - Coating design: Effect of coatings on stress rupture properties of CSMX-2 alloy	224
Figure 48.13-7 - Coating design: Effect of plasma sprayed coating on stress rupture properties of Cotac 784 alloy.....	225
Figure 48.13-8 - Coating design: Typical creep fatigue effects for cooled gas turbine blades	227
Figure 48.15-1 - Superalloys: Space applications – Hot structure.....	229
Figure 49.6-1 - Titanium aluminides: Effect of temperature on Young’s modulus.....	252
Figure 49.6-2 - Titanium aluminides: Two-phase alloys - Ductility versus temperature	253
Figure 49.6-3 - Titanium aluminides: Comparison of fatigue characteristics with Rene 95 superalloy.....	254
Figure 49.6-4 - Titanium aluminides: Two-phase alloys – Thermal diffusivity versus temperature.....	256
Figure 49.6-5 - Titanium aluminides: Two-phase alloys – Specific heat versus temperature.....	257
Figure 49.6-6 - Titanium aluminides: Two-phase alloys – Thermal conductivity versus temperature.....	258
Figure 49.6-7 - Titanium aluminides: Two-phase alloys – Coefficient of thermal expansion versus temperature	260
Figure 49.7-1 - Iron aluminides: Room temperature behaviour of Fe-40Al(at. %) + boron additions in different conditions	262
Figure 49.7-2 - Iron aluminides: Effect of conditioning and elevated temperature on strength of Ytria ODS alloy system.....	263
Figure 49.10-1 - Intermetallic matrix composites: Characteristics of orthorhombic phase titanium aluminide matrix	271
Figure 49.10-2 - Intermetallic matrix composites: TiAl/SiC composite - Insamet ‘foil-fibre-foil’ processing steps.....	273
Figure 49.11-1 - Intermetallics: Potential applications - Elevated temperature specific strengths of materials	275
Figure 49.11-2 - Intermetallics: Potential applications - Outer skin structures for space applications	276
Figure 51.4-1 - Beryllium S-200 grades: Effect of temperature on 0.2% yield strength	289
Figure 51.4-2 - Beryllium S-200 grades: Effect of temperature on ultimate tensile strength.....	289
Figure 51.4-3 - Beryllium S-200 grades: Effect of temperature on elongation	290
Figure 51.4-4 - Beryllium: Effect of temperature on thermal conductivity	292
Figure 51.4-5 - Beryllium: Effect of temperature on diffusivity	292

Figure 51.4-6 - Beryllium: Effect of temperature on expansion	293
Figure 51.4-7 - Beryllium: Effect of temperature on specific heat capacity	294
Figure 52.2-1 - CMC composite development	298
Figure 52.2-2 - CMC composite development: Material combinations	301
Figure 52.3-1 - Ceramic matrix composites: C-SiC load versus displacement curves at RT and 1600°C	305
Figure 52.3-2 - C/SiC LPI (EADS-ST): Manufacturing and inspection flow chart	307
Figure 52.3-3 - C/SiC LPI (EADS-ST): Specific heat capacity.....	309
Figure 52.3-4 - C/SiC LPI (EADS-ST): Thermal conductivity	310
Figure 52.3-5 - C/SiC LPI (EADS-ST): Surface emittance, with anti-oxidation coating.....	311
Figure 52.3-6 - C/SiC LPI (EADS-ST): Architecture of multi-layer, self-healing OPS	312
Figure 52.3-7 - C/SiC LPI (EADS-ST): Function of layers in OPS.....	313
Figure 52.3-8 - C/C-SiC LSI (DLR): Mechanical properties for XT and XB grades.....	315
Figure 52.5-1 - SiC-SiC composites: High temperature flexural strength of various compositions	317
Figure 52.5-2 - SiC-SiC composite (bidirectional): Typical tensile stress-strain curve.....	318
Figure 52.5-3 - SiC-SiC composites: Typical bending strength versus temperature profiles compared with C-SiC composite	319
Figure 52.5-4 – SiC-SiC composites: Representative through-thickness fracture toughness versus temperature compared with C-SiC.....	320
Figure 52.7-1 – Ceramic matrix composites: FOLDHOST concept for deployable decelerator	326
Figure 52.7-2 – Ceramic matrix composites: Applications – X-38 body flaps	327
Figure 52.7-3 - Ceramic matrix composites: Applications – Optical communications systems.....	328
Figure 53.5-1 - Glass-ceramic composites: Tensile stress-strain curve for unidirectional (0°) SiC/LAS-II at room temperature.....	347
Figure 53.5-2 - Glass-ceramic composites: Flexural stress-strain curve for SiC/BMAS-III.....	348
Figure 53.5-3 - SiC reinforced glass-ceramic composite: Flexural strength versus temperature for unidirectional SiC/LAS	349
Figure 53.5-4 - SiC reinforced glass-ceramic composite: Flexural strength versus temperature for unidirectional SiC/LAS-III	350
Figure 53.5-5 - SiC reinforced glass-ceramic composite: Compressive stress-strain response of 0°, 0°/90°, and ±45° SiC/LAS-III, at 23°C.....	351
Figure 53.5-6 - SiC reinforced glass-ceramic composite: Flexural stress-strain data for 0°/±45°/90° SiC/LAS for a wide temperature range	351
Figure 53.5-7 - SiC reinforced glass-ceramic composite: Strengths versus temperature for monolithic LAS (Pyroceram) and unidirectional LAS/SiC (Compglas)	352
Figure 53.5-8 - SiC reinforced glass-ceramic composite: Dependence of failure strengths with temperature and loading mode for 0° Compglas and monolithic Pyroceram.....	353

Figure 53.5-9 - SiC reinforced glass-ceramic composite: Comparison of flexural strength under various loading conditions for 0° SiC/LAS at 22°C.....	354
Figure 53.5-10 - SiC reinforced glass-ceramic composite: Comparison of flexural strength under various loading conditions for 0° SiC/LAS at 600°C.....	355
Figure 53.5-11 - SiC reinforced glass-ceramic composite: Comparison of flexural strength under various loading conditions for 0° SiC/LAS at 900°C.....	355
Figure 53.5-12 - SiC reinforced glass-ceramic composite: Room temperature four-point flexural fatigue of 0° SiC/LAS-II	356
Figure 53.5-13 - SiC reinforced glass-ceramic composite: Room temperature tensile fatigue of 0° SiC/LAS-III	357
Figure 53.5-14 - SiC reinforced glass-ceramic composite: Room temperature uniaxial tensile fatigue of 0°/90° SiC/LAS-II and 0°/90° SiC/LAS-III.....	357
Figure 54.2-1 - Carbon-carbon composites: Schematic diagram of material selection and processing routes	364
Figure 54.2-2 - Carbon-carbon composites: 4-D fibre architecture in SEPCARB® 4-D.....	365
Figure 54.2-3 - Carbon-carbon composites: 3-D fibre preforms	365
Figure 54.2-4 - Carbon-carbon composites: Examples of multidirectional fibre preforms.....	366
Figure 54.3-1 - Carbon-carbon composites: Predicted modulus values from conventional theory without a matrix contribution	368
Figure 54.3-2 - Carbon-carbon composites: Tensile response of 3-D composite	369
Figure 54.3-3 - Carbon-carbon composites: Tensile response of 4-D composite	370
Figure 54.6-1 – Carbon-carbon composites: Manufacturing process equipment	376
Figure 54.6-2 – Carbon-carbon composites: GOCE gradiometer	377
Figure 54.6-3 – Carbon-carbon composites: Test cylinders	379
Figure 54.6-4 – Carbon-carbon composites: Pleiades flight cylinder.....	379
Figure 56.3-1 - Metals and MMCs: Stress-strain response compared with CFRP.....	395
Figure 56.3-2 - Metals and ceramic-based materials: Stress-strain response.....	396

Tables

Table 46.2-1 - Aluminium alloys: Comparison of national specifications for wrought alloys.....	32
Table 46.2-2 - Aluminium alloys: Comparison of national specifications for casting alloys.....	34
Table 46.4-1 - Al-Li alloys: Commercial sources and products	39
Table 46.5-1 - Al-Li alloys: Typical properties compared with 7075	41
Table 46.6-1 - Al-Li alloys: Mechanical properties	44
Table 46.6-2 - Al-Li alloys: Fracture properties	46
Table 46.6-3 - Al-Li alloys: Fatigue crack growth rate of 1441 and 1163 sheet.....	50
Table 46.6-4 - Al-Li alloys: Design tensile strengths for extruded 8090 alloys.....	52
Table 46.7-1 - Al-Li alloys: Alloy 8090 - Results of stress corrosion tests	54

Table 46.7-2 - Al-Li alloys: Tentative stress corrosion thresholds for 8090 alloy	55
Table 46.7-3 - Al-Li alloys: Results of stress corrosion test on sheet material, as performed by NLR.....	55
Table 46.7-4 - Al-Li Alloys: SCC initiation behaviour of 8090 alloy compared with that of conventional alloys	55
Table 46.7-5 - Al-Li alloys: Current commercial alloys – summary of corrosion resistance.....	56
Table 46.8-1 – Al-Li alloys: 2195-T8 plate and weldments - summary of fatigue crack growth rate	58
Table 46.9-1 – Al-Li alloys: Applications – mass savings in Space Shuttle external tank.....	60
Table 46.11-1 - RSP aluminium alloys: Ambient temperature use - nominal alloy compositions	73
Table 46.11-2 - RSP aluminium alloys: Ambient temperature use -tensile properties	73
Table 46.11-3 - RSP aluminium alloys: Elevated temperature - modified property goals (minimum values) for shaped extrusions of P/M alloy CZ42.....	74
Table 46.11-4 - RSP aluminium alloys: Room and elevated temperature tensile properties of planar flow cast alloy FVS-0812	75
Table 46.11-5 - RSP aluminium alloys: Room and elevated temperature tensile properties of alloy FVS-1212	75
Table 46.11-6 - RSP aluminium alloys: Elastic modulus, density and weight-saving parameters for thermally stable RS-P/M alloys.....	75
Table 46.12-1 – Al-MMCs: Summary of suppliers and capabilities	79
Table 46.13-1 – Al-MMCs: Typical properties of SiB6 silicon hexaboride particulate reinforcement – Hexon®	82
Table 46.13-2 – Al-MMCs: Typical properties of constituents used for MMCC MetGraf™ Al/Cf composites	83
Table 46.14-1 – Al-MMC’s: Room temperature properties of AMC225xe and AMC640xa	86
Table 46.14-2 – Al-MMC’s: Elevated temperature properties of AMC225xe plate.....	87
Table 46.14-3 – Al-MMC’s: Elevated temperature properties of extruded AMC225xe compared with Duralcan® MMC's	88
Table 46.14-4 – Al-MMC’s: Typical room temperature properties of DWA 2009/SiCp and 6092/SiCp composites	89
Table 46.14-5 – Al-MMC’s: Typical room temperature tensile properties of DWA 2009/SiCp extruded composites.....	90
Table 46.14-6 – Al-MMC’s: Typical properties of CPS Al/SiCp composites	93
Table 46.14-7 – Al-MMC’s: Typical room temperature properties of TTC Al/SiCp composites.....	94
Table 46.14-8 – Al-MMC’s: Typical properties of composites from M Cubed Technologies.....	95
Table 46.14-9 – Al-MMC’s: Typical properties of MMCC METSIC™ Al/SiCp composite compared with aluminium and steel	96

Table 46.14-10 – Al-MMC’s: Typical properties of Millenium Materials Carolite® SiB ₆ particulate reinforced composites	97
Table 46.14-11 – Al-MMC’s: Typical room temperature properties of MMCC MetGraf™ Al/Cf composites	98
Table 46.14-12 – Al-MMC’s: Typical properties of MMCC MetGraf™ Al/Cf composites compared with other thermal packaging materials.....	99
Table 46.14-13 – Al-MMC’s: Properties of Osprey CE Al-Si ‘in-situ composite’ alloys	100
Table 46.15-1 – Al-MMC’s: Typical properties of continuous reinforcing fibres	102
Table 46.15-2 – Al-MMC’s: Typical properties of 3M Nextel™ 610 alumina fibre.....	103
Table 46.16-1 – Al-MMC’s: Typical properties of continuously reinforced MMCs.....	107
Table 46.16-2 – Al-MMC’s: Typical properties of 3M unidirectional Al-Nextel□ composites.....	108
Table 46.16-3 – Al-MMC’s: Typical properties of 3M MMC push rods	109
Table 46.16-4 – Al-MMC’s: Typical properties of TRL MetPreg™ Al/Al ₂ O ₃ f continuous fibre composites	110
Table 47.2-1 - Titanium alloys: Effects of alloying elements on microstructure	127
Table 47.2-2 - Titanium alloys: Influence of processing temperatures on near- α alloys	128
Table 47.2-3 - Titanium alloys for aerospace use: Characteristics	128
Table 47.2-4 - Titanium alloys: Indicative mechanical properties	131
Table 47.2-5 - Titanium alloys: Physical properties.....	137
Table 47.7-1 - Titanium matrix composites: Typical room temperature tensile properties	145
Table 47.7-2 - Titanium matrix composites: Typical strengths of UD SIGMA SiC reinforced alloys	146
Table 47.7-3 - Titanium matrix composites: Fatigue properties.....	147
Table 47.8-1 - Titanium alloys: Effect of hydrogen.....	150
Table 47.9-1 - Titanium alloys: Ignition and burn characteristics.....	151
Table 47.10-1 - Titanium alloys: Potential coating systems	152
Table 48.2-1 - Superalloys: Property requirements for engine components.....	161
Table 48.2-2 - Superalloys: For aero-engine component applications	163
Table 48.2-3 - Superalloys: Typical mechanical properties.....	164
Table 48.2-4 - Superalloys: Comparison of rocket engine and aircraft engine turbine operation	169
Table 48.2-5 - Superalloys: Potential blade materials under evaluation for rocket engine turbine components	170
Table 48.2-6 - Single crystal superalloys: Potential use in rocket engine turbines	171
Table 48.3-1 - Reinforcing phases in directionally solidified (DS) eutectic superalloys	172
Table 48.3-2 - Directionally solidified (DS) superalloys.....	172
Table 48.3-3 - Single crystal (SC) superalloys	173
Table 48.3-4 - Powder metallurgy of superalloys	174

Table 48.3-5 - Powder metallurgy nickel-based superalloys: Composition.....	174
Table 48.3-6 - Oxide dispersion strengthened (ODS) superalloys: Composition.....	175
Table 48.5-1 - Superalloy composites: Reinforcement phases	178
Table 48.5-2 - Superalloys: Typical mechanical properties of matrix materials for composites.....	179
Table 48.6-1 - Tungsten fibre reinforced composites: Reinforcement and superalloy matrix	180
Table 48.6-2 - Tungsten fibre reinforced, nickel-based superalloys: Tensile properties of development composites.....	181
Table 48.6-3 - Tungsten fibre reinforced, cobalt-based superalloys: Tensile properties of development composites.....	182
Table 48.6-4 - Tungsten fibre reinforced, iron-based superalloys: Tensile properties of development composites.....	183
Table 48.6-5 - Tungsten fibre reinforced superalloy: Room temperature tensile strength of thermally cycled composite.....	185
Table 48.6-6 - Summary of tungsten fibre reinforced superalloy (TFRS) systems	186
Table 48.7-1 - Established mechanisms of hydrogen degradation in materials.....	187
Table 48.7-2 - Characteristics of hydrogen environment embrittlement (HEE).....	188
Table 48.7-3 - Sensitivity of superalloys to hydrogen.....	189
Table 48.7-4 - Effect of hydrogen on MAR-M-246 superalloys.....	190
Table 48.7-5 - Effect of crystal anisotropy on RT hydrogen performance of PWA 1480 single crystal alloy	190
Table 48.7-6 - Effect of hydrogen on directionally solidified eutectic (DSE) and oxide dispersion strengthened (ODS) superalloys	191
Table 48.7-7 - Low cycle fatigue (LCF) life degradation of superalloys in hydrogen environments	197
Table 48.8-1 - Ignition and burn characteristics of materials in oxygen environments.....	202
Table 48.10-1 - Diffusion coatings for superalloys: Various types and use	205
Table 48.10-2 - Diffusion coatings: Commercially available types	207
Table 48.11-1 - Commercially available MCrAlY overlay coatings	208
Table 48.11-2 - Overlay coatings: Later studies with MCrAlY type coatings and superalloys substrates.....	209
Table 48.12-1 - Thermal barrier coatings: Material systems	210
Table 48.12-2 - Thermal barrier coating technology: Later studies	210
Table 48.13-1 - Coating design: Factors associated with coating systems for oxidation and corrosion resistance	211
Table 48.13-2 - Coating design: Comparison of technical factors for diffusion and overlay coatings	212
Table 48.13-3 - Coating design: Tensile properties of coated material systems	217
Table 48.13-4 - Coating design: Fatigue properties of coated material systems	219
Table 48.13-5 - Coating design: Creep properties of coated material systems	226

Table 49.2-1 - Intermetallic compounds: Comparison of aluminide groups	235
Table 49.3-1 - Nickel aluminides: Characteristics of NiAl and Ni ₃ Al intermetallic compounds	238
Table 49.3-2 - Nickel aluminides: Compositions (based on Ni ₃ Al) under development	239
Table 49.3-3 - Nickel aluminides: Composition, material designation and sources	239
Table 49.4-1 - Nickel aluminides: Mechanical properties at elevated temperatures with various conditioning	241
Table 49.4-2 - Nickel aluminides: Modulus at elevated temperature	242
Table 49.4-3 - Nickel aluminides: Preliminary fatigue test data for IC218 and IC221	243
Table 49.4-4 - Nickel aluminides: Coefficient of thermal expansion	244
Table 49.5-1 - Titanium aluminides: Comparison of characteristics	245
Table 49.5-2 - Titanium aluminides: Typical compositions	246
Table 49.6-1 - Titanium aluminides: Mechanical properties for materials processed by different techniques	248
Table 49.6-2 - Titanium aluminides: Indication of creep properties	255
Table 49.7-1 - Iron aluminides: Characteristics	261
Table 49.7-2 - Iron aluminides: Composition of development materials	261
Table 49.8-1 - Aluminides: Summary of manufacture and consolidation techniques	264
Table 49.9-1 - Further development: Intermetallic compounds	267
Table 49.10-1 - Intermetallic matrix composites: Summary of compounds and reinforcements	269
Table 49.10-2 - Intermetallic matrix composites: Requirements for a reinforcement fibre	269
Table 50.2-1 - Refractory and precious metals: Attributes and disadvantages	281
Table 50.2-2 - Refractory and precious metals: Basic physical properties	281
Table 50.2-3 - Refractory metal alloys: Examples	282
Table 51.2-1 - Beryllium: Characteristics	283
Table 51.3-1 – Beryllium: Grades	285
Table 51.4-1 - Beryllium grades: Composition and tensile properties	287
Table 51.4-2 - Beryllium grades S-200-F and SR-200-E: Mechanical properties at various temperatures	288
Table 51.4-3 - Beryllium: Effect of temperature on modulus and physical properties	291
Table 52.2-1 - Ceramic matrix composites: Fibre and matrix combinations with sources of development/investigation	299
Table 52.2-2 - Development continuous fibre reinforced ceramic matrix composites: Typical properties	302
Table 52.3-1 - Ceramic matrix composites: Typical properties of C-SiC composites produced by different processing methods	305
Table 52.3-2 - C/SiC LPI (EADS-ST): Fabrication and inspection steps	307
Table 52.3-3 - C/SiC LPI (EADS-ST): Mechanical properties at different temperatures	309

Table 52.3-4 - C/SiC LPI (EADS-ST): OPS used in OLCHOS programme	313
Table 52.3-5 - C/C-SiC LSI (DLR): Mechanical properties for different grades	314
Table 52.5-1 - SiC-SiC composites: Indicative properties, as measured by SEP (France)	320
Table 52.6-1 - Ceramic matrix composites: Ceramic whiskers.....	321
Table 52.6-2 - Ceramic matrix composites: Development whisker and matrix combinations	323
Table 53.2-1 - Glass and glass-ceramic matrices	338
Table 53.3-1 - Carbon fibre/borosilicate unidirectional composites: Mechanical properties	341
Table 53.3-2 - Unidirectional and angle-ply tensile data for Hercules HMU carbon fibre reinforced 7740 borosilicate glass composite	342
Table 53.3-3 - Mechanical test data for notched 0/90° reinforced HMU/7740 composites	343
Table 53.4-1 - SiC reinforced glass-ceramic composites: Comparison of RT unidirectional (0°) properties with SiC fibre reinforced epoxy.....	345
Table 54.3-1 - Carbon-carbon composites: Indicative mechanical properties	367
Table 54.4-1 - Carbon-carbon composites: Requirements for oxidation protection systems for two applications.....	372
Table 54.6-1 – Carbon-carbon composites: Basic properties	375
Table 55.6-1 - Advanced metals and ceramics: Significant European sources of expertise	387
Table 55.7-1 - Advanced metals and ceramics: Direct material costs	389
Table 55.7-2 - Advanced metals and ceramics: Relative costs of components	390
Table 57.2-1 - Advanced metal- and ceramic-based materials: Relevance of space parameters to material selection	405
Table 58.2-1 - Dissimilar materials for joints	411
Table 59.2-1 - Joints between dissimilar materials: Representative list of materials	420
Table 60.2-1 - Comparison of jointing and consolidation techniques	423
Table 60.3-1 - Fused joints: Technology review of joints	425
Table 60.3-2 - Fusion joints: Published bond strengths for various joints.....	427

European Foreword

This document (CEN/TR 17603-32-05:2022) has been prepared by Technical Committee CEN/CLC/JTC 5 "Space", the secretariat of which is held by DIN.

It is highlighted that this technical report does not contain any requirement but only collection of data or descriptions and guidelines about how to organize and perform the work in support of EN 16603-32.

This Technical report (CEN/TR 17603-32-05:2022) originates from ECSS-E-HB-32-20 Part 5A.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

This document has been developed to cover specifically space systems and has therefore precedence over any TR covering the same scope but with a wider domain of applicability (e.g.: aerospace).

Introduction

The Structural materials handbook is published in 8 Parts.

A glossary of terms, definitions and abbreviated terms for these handbooks is contained in Part 8.

The parts are as follows:

TR 17603-32-01	Part 1	Overview and material properties and applications	Clauses 1 - 9
TR 17603-32-02	Part 2	Design calculation methods and general design aspects	Clauses 10 - 22
TR 17603-32-03	Part 3	Load transfer and design of joints and design of structures	Clauses 23 - 32
TR 17603-32-04	Part 4	Integrity control, verification guidelines and manufacturing	Clauses 33 - 45
TR 17603-32-05	Part 5	New advanced materials, advanced metallic materials, general design aspects and load transfer and design of joints	Clauses 46 - 63
TR 17603-32-06	Part 6	Fracture and material modelling, case studies and design and integrity control and inspection	Clauses 64 - 81
TR 17603-32-07	Part 7	Thermal and environmental integrity, manufacturing aspects, in-orbit and health monitoring, soft materials, hybrid materials and nanotechnologies	Clauses 82 - 107
TR 17603-32-08	Part 8	Glossary	

46 Aluminium alloys and their composites

46.1 Introduction

46.1.1 General

[Aluminium](#) alloys are established in aerospace, with many years of application and service experience.

Alloy developments are described that have aimed at improving the mechanical characteristics of basic aluminium alloys and the limitations on service temperature.

The ability to improve dimensional stability by combining alloys with low [CTE](#) materials is an advantage for space use.

The materials described are divided into the main groups:

- Conventional aluminium alloys.
- New aluminium alloys.
- MMC – metal matrix composites.
- FML – fibre metal laminates

46.1.2 Conventional aluminium alloys

In recent years it has become clear that many of the problems associated with conventional aluminium alloys, e.g. inconsistent fracture properties, were associated with the nature, size, morphology and distribution of intermetallic particles, both intended (as the strengthening phase) and unintended (from tramp elements). Attention has therefore focussed on improving both alloy chemistry and process technology to give more desirable structures in the finished material. In addition to alloy modifications, this has resulted in the introduction of modified thermo-mechanical treatments (combinations of heat treatments and hot or cold working) with new temper designations, which are expansions of the basic tempers, [See: [46.2](#)].

Specific data on conventional aluminium alloys are not given in this handbook, [See: MMPDS-01 and PMP], Ref. [\[46-71\]](#), [\[46-72\]](#).

46.1.3 New aluminium alloys

These can be grouped as:

- Aluminium-[lithium](#) (Al-Li) alloys. [See: [46.4](#)]
- [Powder metallurgy](#) (P/M) alloys: