

SLOVENSKI STANDARD
SIST-TP CEN/TR 17603-32-07:2022

01-marec-2022

Vesoljska tehnika - Priročnik o strukturnih materialih - 7. del: Toplotna in okoljska celovitost, proizvodni vidiki, spremljanje stanja materialov v orbiti, mehki materiali, hibridni materiali in nanotehnologije

Space engineering - Structural materials handbook - Part 7: Thermal and environmental integrity, manufacturing aspects, in-orbit and health monitoring, soft materials, hybrid materials and nanotechnologies

The STANDARD

Raumfahrttechnik - Handbuch der Strukturwerkstoffe - Teil 7: Thermische und umweltbedingte Integrität, Herstellungsaspekte, In-Orbit- und Gesundheitsüberwachung, weiche Werkstoffe, Hybridwerkstoffe und Nanotechnologien
(standards.itch.ai)

Ingénierie spatiale - Manuel des matériaux structuraux - Partie 7 : Intégrité thermique et en environnement, aspects de fabrication, surveillance des matériaux, matériaux souples, matériaux hybrides et nanotechnologies
<https://www.sist.si/standards/04bc287d1/sist-tp-cen-tr-17603-32-07-2022>

Ta slovenski standard je istoveten z: CEN/TR 17603-32-07:2022

ICS:

49.140 Vesoljski sistemi in operacije Space systems and operations

SIST-TP CEN/TR 17603-32-07:2022 en,fr,de

**iTeh STANDARD
PREVIEW
(standards.iteh.ai)**

[SIST-TP CEN/TR 17603-32-07:2022](#)

<https://standards.iteh.ai/catalog/standards/sist/1f0283ec-39cd-4819-990a-5de04bc287d1/sist-tp-cen-tr-17603-32-07-2022>

**TECHNICAL REPORT
RAPPORT TECHNIQUE
TECHNISCHER BERICHT**

CEN/TR 17603-32-07

January 2022

ICS 49.140

English version

Space engineering - Structural materials handbook - Part 7: Thermal and environmental integrity, manufacturing aspects, in-orbit and health monitoring, soft materials, hybrid materials and nanotechnologies

Ingénierie spatiale - Manuel des matériaux structuraux

- Partie 7 : Intégrité thermique et en environnement, aspects fabrication, surveillance des matériaux, matériaux souples, matériaux hybrides et nanotechnologies

Raumfahrttechnik - Handbuch der Strukturwerkstoffe -

- Teil 7: Thermische und umweltbedingte Integrität, Herstellungsaspekte, In-Orbit- und Gesundheitsüberwachung, weiche Werkstoffe, Hybridwerkstoffe und Nanotechnologien

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

**iTeh STANDARD
PREVIEW
(Standards.Iteh.ai)**

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, Switzerland, Turkey and United Kingdom.

SIST-TP CEN/TR 17603-32-07:2022

<https://standards.iteh.ai/catalog/standards/sist/1f0283ec-39cd-4819-990a-5de04bc287d1/sist-tp-cen-tr-17603-32-07-2022>



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

Table of contents

European Foreword.....	30
Introduction.....	31
82 Thermal behaviour	32
82.1 Introduction.....	32
82.1.1 General.....	32
82.1.2 Physical response	32
82.1.3 Physical properties	32
82.2 MMC: Thermal cycling	33
82.2.1 General.....	33
82.2.2 Magnesium-carbon fibre composites	33
82.2.3 Aluminium-carbon fibre composites	34
82.2.4 Aluminium-boron filament composites	34
82.2.5 Titanium-silicon carbide filament composites	35
82.2.6 Superalloy (FeCrAlY) composites	35
82.3 CMC: Thermal cycling	35
82.4 MMC: Thermal shock.....	36
82.4.1 General.....	36
82.4.2 Metal alloys	36
82.4.3 MMC.....	36
82.4.4 Intermetallics	36
82.5 CMC: Thermal shock	36
82.5.1 General.....	36
82.5.2 SiC-SiC composites	37
82.6 MMC: Thermal conductivity	38
82.6.1 General.....	38
82.6.2 Thermal diffusivity measurement	38
82.6.3 Effect of material composition	38
82.6.4 Modelling	39
82.7 CMC: Thermal conductivity	40
82.7.1 General.....	40

82.7.2 Glass-ceramic matrix composites	40
82.7.3 SiC-SiC and C-SiC composites.....	41
82.8 Specific heat capacity	48
82.9 Surface emissivity.....	48
82.10 Surface catalyticity.....	49
82.11 References	49
82.11.1 General.....	49
83 Thermo-mechanical fatigue.....	52
83.1 Introduction.....	52
83.2 Phased TMF	52
83.3 Superalloys.....	53
83.4 Aluminium composites	53
83.4.1 Particulate reinforced composites	53
83.4.2 Continuous fibre reinforced composites	54
83.5 Titanium composites.....	54
83.6 Copper composites.....	57
83.7 Ceramic composites	58
83.8 Carbon-carbon composites.....	58
83.9 Predictive methods.....	58
83.10 References	59
83.10.1 General.....	59
SIST-TP CEN/TR 17603-32-07:2022 https://standards.iteh.ai/catalog/standards/sist/1f0283ec-39cd-4819-990a-5de04bc287d1/sist-tp-cen-tr-17603-32-07-2022	
84 Dimensional control.....	62
84.1 Introduction.....	62
84.2 Residual stresses	62
84.3 Creep: Metallic materials	62
84.3.1 General.....	62
84.3.2 Particulate reinforced aluminium composites	63
84.3.3 Discontinuous fibre reinforced aluminium	63
84.4 Creep: Ceramic composites.....	63
84.4.1 General.....	63
84.4.2 Creep mismatch ratio (CMR)	63
84.5 Crack densities	66
84.6 CTE: Metallic materials	66
84.6.1 General.....	66
84.6.2 Continuous reinforcement.....	66
84.6.3 Particulate reinforcement.....	67
84.7 CTE: Ceramic composites	67

CEN/TR 17603-32-07:2022 (E)

84.7.1 SiC matrix composites	67
84.7.2 Glass matrix composites.....	70
84.7.3 Environmental factors	70
84.8 References	70
84.8.1 General.....	70
85 High-temperature environmental stability	72
85.1 Introduction.....	72
85.2 Aqueous corrosion: Metals	72
85.2.1 General.....	72
85.2.2 Aluminium-based composites	72
85.3 Hot corrosion: Metals	73
85.3.1 Applications	73
85.3.2 Causes	73
85.3.3 Protection systems	74
85.4 Hot corrosion: CMC	74
85.4.1 Causes	74
85.5 Oxidation: Metals	74
85.6 Oxidation: Ceramics	74
85.6.1 Carbon-containing materials	74
85.6.2 SiC-SiC composites.....	75
85.6.3 Chemical reactions	76
85.6.4 Effect of conditions	76
85.6.5 Effect of manufacturing route	76
85.6.6 Modelling	77
85.7 Hydrogen embrittlement.....	77
85.7.1 General.....	77
85.7.2 Metal-based materials	77
85.7.3 Ceramic-based materials	78
85.7.4 Precautions	78
85.8 Hydrogen: Titanium materials	79
85.8.1 General.....	79
85.8.2 Alloys.....	79
85.8.3 MMC	80
85.9 Hydrogen: Intermetallic materials	80
85.9.1 Titanium aluminides	80
85.10 Hydrogen: Carbon composites.....	82
85.11 References	82

85.11.1 General	82
86 High-temperature test facilities	85
86.1 Introduction	85
86.2 Thermo-mechanical loading	86
86.2.1 General	86
86.2.2 Spaceplane verification	86
86.2.3 Test facilities	86
86.3 Thermo-acoustic testing	87
86.3.1 General	87
86.3.2 Test facilities	87
86.4 Plasma arc jet tests	87
86.4.1 General	87
86.4.2 Test facilities	87
86.5 Electric arc jet tests	87
86.5.1 General	87
86.5.2 Test facilities	88
86.6 Oxygen-hydrogen combustors	88
86.7 European facilities	88
86.7.1 General	88
86.7.2 France	88
86.7.3 Germany	89
86.7.4 Switzerland	89
86.7.5 Austria	89
86.7.6 UK	90
86.7.7 The Netherlands	90
86.7.8 Belgium	90
86.7.9 Russia	90
86.8 References	90
86.8.1 General	90
87 Integrated manufacturing	93
87.1 Introduction	93
87.2 Process development	93
87.2.1 Techniques	93
87.2.2 Status	93
87.2.3 Expertise	93
87.3 Stages in manufacture	94
87.3.1 Process techniques	94

CEN/TR 17603-32-07:2022 (E)

87.3.2 Finishing	95
87.3.3 Surface protection and coatings	95
88 Manufacturing techniques.....	96
88.1 Introduction.....	96
88.2 Composite manufacture.....	96
88.2.1 Matrix phase	96
88.2.2 Reinforcement	98
88.2.3 Processing.....	98
88.3 Powder processing	98
88.3.1 Metals.....	98
88.3.2 MMC	99
88.4 Sintering	101
88.5 Hot isostatic pressing (HIP)	101
88.6 Foil and fibre consolidation	101
88.6.1 General.....	101
88.6.2 Metal foils	102
88.6.3 Powder cloth.....	102
88.7 Superplastic forming (SPF).....	103
88.7.1 Metal characteristics	103
88.7.2 Techniques	103
88.8 Diffusion bonding (DB).....	105
https://standards.iteh.ai/catalog/standards/sist/1f0283ec-9cd-4819-990a-5de04bc287d1/sist-tp-cen-tr-17603-32-07-2022	
88.9 Hot pressing.....	106
88.9.1 MMC.....	106
88.9.2 Glass and ceramic-based composites	106
88.10 Diffusion coatings	106
88.10.1 General	106
88.10.2 Pack cementation	106
88.10.3 Chromising.....	107
88.10.4 Aluminising	108
88.10.5 Selective oxidation	109
88.10.6 Modified native oxides	109
88.11 Reaction bonding.....	109
88.12 Polymer or pitch infiltration and pyrolysis	110
88.13 Melt infiltration	111
88.13.1 General	111
88.13.2 Metal matrix	111
88.13.3 Glass matrix	113

88.13.4 Ceramic matrix.....	114
88.14 In-situ siliconising.....	114
88.14.1 Molten	114
88.14.2 Particulate	114
88.15 In-situ oxidation	114
88.15.1 MMC to ceramic oxide matrix.....	114
88.15.2 Oxide coatings on metals	115
88.15.3 Oxide coatings on ceramics	115
88.16 Sol-gel	115
88.17 Slurry infiltration.....	118
88.18 Investment casting.....	120
88.19 Spray techniques.....	122
88.19.1 Atomisation	122
88.19.2 Plasma spraying	122
88.20 Physical vapour deposition (PVD).....	125
88.20.1 Coatings.....	125
88.21 Chemical vapour deposition (CVD)	127
88.22 Chemical vapour infiltration (CVI)	128
88.23 References	131
88.23.1 General	131
89 European sources of expertise.....	134
https://standards.iteh.ai/catalog/standards/sist/110283ec-39cd-4819-990a-5de04bc287d1/sist-tp-cen-tr-17603-32-07-2022	
89.1 Introduction	134
89.2 Company specialisation	135
89.2.1 General.....	135
89.2.2 Aerospatiale	135
89.2.3 Societe Européene de Propulsion (SEP)	136
89.2.4 ONERA : L'Office National d'Etudes et de Recherches Aerospatiale	136
89.2.5 Le Carbone	136
89.2.6 SNECMA	136
89.2.7 Dassault Aviation	136
89.2.8 Dornier Luftfahrt GmbH	136
89.2.9 Dornier Deutsche Aerospace	136
89.2.10 MAN Technologie AG	137
89.2.11 SIGRI	137
89.2.12 MBB (DASA)	137
89.2.13 MTU Motoren und Turbinen Union GmbH	137
89.2.14 Sintec Keramik.....	137

CEN/TR 17603-32-07:2022 (E)

89.2.15 Deutche Forschunganstalt fur Luft und Raumfahrt (DLR).....	137
89.2.16 British Aerospace (BAe).....	137
89.2.17 Rolls Royce.....	137
89.2.18 Dunlop Aviation	137
89.2.19 BP Metal Composites Ltd.....	137
89.2.20 British Alcan	138
89.2.21 AEA Technology (Harwell)	138
89.2.22 Magnesium Elektron Ltd	138
89.2.23 Defence Research Agency (DRA).....	138
89.2.24 Stork Product Engineering BV.....	138
89.2.25 Volvo Flygmotor AB	138
89.2.26 Raufoss A/S	138
89.2.27 Battelle	138
89.2.28 Saab Ericsson Space	138
90 Smart technologies	139
90.1 Introduction	139
90.1.1 Smart materials, technologies and systems	139
90.1.2 European space structures	139
90.1.3 Condition and health monitoring	141
90.2 Smart terminology.....	141
90.2.1 General.....	141
90.2.2 Smart system levels.....	141
90.2.3 Application	142
90.3 Space requirements for smart systems	142
90.3.1 General.....	142
90.3.2 Damage detection and self-diagnostics	142
90.3.3 Vibration damping.....	144
90.3.4 Active compensation and alignment	144
90.4 Elements of a smart system.....	144
90.4.1 General.....	144
90.4.2 Sensors	145
90.4.3 Actuators	146
90.4.4 Control mechanism.....	146
90.4.5 Immediacy	146
90.4.6 Structural materials.....	146
90.4.7 Structures	146
90.5 Key issues for success	147

90.6 References	147
90.6.1 General.....	147
91 Smart system constituents	149
91.1 Overview	149
91.1.1 Introduction.....	149
91.1.2 Application classes for sensors and actuators	149
91.1.3 Types of smart materials	150
91.2 Sensors	153
91.2.1 General.....	153
91.2.2 Strain gauges	154
91.2.3 Thermocouples.....	154
91.2.4 Accelerometers.....	155
91.2.5 Microsensors	155
91.3 Piezoelectric sensors	156
91.3.1 Features	156
91.3.2 Materials	156
91.3.3 Terminology	156
91.3.4 Manufacture	157
91.3.5 Properties	157
91.4 Fibre optic sensors (FOS).....	160
91.4.1 Features	160
91.4.2 Types of fibre optic sensors (FOS)	161
91.4.3 Technical background	164
91.4.4 Interferometers	167
91.4.5 Bragg grating	169
91.4.6 Backscattering	169
91.4.7 Optical time domain reflectometry (OTDR)	170
91.4.8 Uses for fibre optics	171
91.5 Actuators	174
91.5.1 Introduction.....	174
91.5.2 Shape memory alloys (SMA)	174
91.5.3 SMA materials	177
91.5.4 Piezoelectric ceramics	182
91.5.5 Piezoceramic actuators	182
91.5.6 Electrostrictive	185
91.5.7 Magnetostrictive	186
91.5.8 ER electrorheological fluids	186

iTeh STANDARD**PREVIEW
(standards.iteh.ai)**SIST-TP CEN/TR 17603-32-07:2022<https://standards.iteh.ai/catalog/standards/sist/1f0283ec-><https://standards.iteh.ai/catalog/standards/sist/1f0283ec-32-07-2022>

CEN/TR 17603-32-07:2022 (E)

91.6 System complexity.....	190
91.6.1 General.....	190
91.6.2 Passive sensory smart materials and structures (Level 1)	190
91.6.3 Smart skins (Level 1).....	191
91.6.4 Reactive actuator-based smart structures (Level 2).....	192
91.6.5 Active sensing and reactive smart structures (Level 3)	193
91.6.6 Active compensation (Level 3).....	193
91.7 Data manipulation, simulation and control systems.....	194
91.7.1 General.....	194
91.7.2 Complexity levels.....	194
91.7.3 System development and integration.....	194
91.7.4 Simulation.....	195
91.7.5 Emerging technologies	197
91.8 Integrated systems	198
91.8.1 Overview	198
91.8.2 Health monitoring.....	198
91.9 EAP electroactive polymers.....	200
91.9.1 Introduction.....	200
91.9.2 Ionic EAPs.....	201
91.9.3 Electronic EAPs.....	203
91.9.4 Others.....	204
91.10 References.....	204
91.10.1 General.....	204
92 Potential space applications	210
92.1 Introduction.....	210
92.2 Perceptions of aerospace requirements.....	210
92.2.1 Aircraft smart skin configurations	210
92.2.2 Helicopter rotor blades.....	211
92.2.3 Detection of ice build-up (Location detector).....	211
92.2.4 Composite cure monitoring	212
92.2.5 Composite structure embedded communications networks	212
92.3 Level 1: Condition and health monitoring	213
92.3.1 General.....	213
92.3.2 Objectives.....	214
92.3.3 Approach	214
92.3.4 Applications	216
92.3.5 Techniques.....	216

92.3.6 Cryogenic tanks	218
92.3.7 Thermal protection systems (TPS).....	220
92.3.8 Structural components	221
92.3.9 Long-term deployed structures	222
92.4 Level 2: Deployment	222
92.4.1 Requirements	222
92.4.2 Shape memory alloys	222
92.5 Level 3: Vibration damping	228
92.5.1 Requirements	228
92.5.2 Active damping with piezoceramic actuators.....	229
92.5.3 SMA wires embedded in composites	230
92.5.4 Application of PVDF layers to structures.....	232
92.5.5 Actuator material coated fibre optic sensors	235
92.6 Level 3: Active compensation and alignment	235
92.6.1 Objectives.....	235
92.7 Application examples	237
92.7.1 General.....	237
PREVIEW	
92.7.2 Sunshields	238
92.7.3 Solar sails	239
92.7.4 Inflatable structures	240
92.7.5 Dynamic control.....	241
https://standards.iteh.ai/catalog/standards/sist/1f0283ec-39cd-4819-990a-5de04bc28/d1/sist-tp-cen-tr-17603-32-07:2022	
92.7.6 Antenna membranes for RF applications	242
92.7.7 Solar arrays and solar generators	242
92.7.8 Shape control of ultra-light-weight mirrors.....	245
92.7.9 Shutters for optical and thermal applications	246
92.7.10 Membrane components	247
92.7.11 Active surface control and sensor applications	248
92.8 References	248
92.8.1 General.....	248
93 Limitations of smart technologies	252
93.1 Introduction.....	252
93.2 Smart system development	252
93.2.1 Sensors	252
93.2.2 Actuators	253
93.2.3 Control systems	254
93.3 Durability and longevity	254
93.3.1 Sensors	254

CEN/TR 17603-32-07:2022 (E)

93.3.2 Actuators	255
93.4 Redundancy to guaranteed operational life.....	255
93.4.1 General.....	255
93.4.2 Sensors and actuators	255
93.4.3 Control systems	255
93.5 System mass and efficiency	256
93.5.1 General.....	256
93.5.2 Actuators	256
93.6 Smart system development for European space programmes	256
93.6.1 Background	256
93.6.2 On-going programmes.....	257
93.7 References	257
93.7.1 General.....	257
94 European capabilities in smart technologies	258
94.1 Introduction.....	258
94.2 Smart technology survey	258
94.3 European expertise	263
94.3.1 Smart technologies	263
94.3.2 Structural health monitoring	265
94.4 References	269
94.4.1 General.....	269
https://standards.iteh.ai/catalog/standards/sist/f0283ec-39cd-4819-990a-5de04bc287d1/sist-tp-cen-tr-17603-32-07-2022	
95 Textiles	275
95.1 Introduction.....	275
95.1.1 General.....	275
95.1.2 Fibre types and combinations	275
95.1.3 Fibre properties	275
95.1.4 Textiles in spacecraft	276
95.1.5 Testing of textiles.....	278
95.2 Terminology.....	278
95.2.1 Textile terms	278
95.3 Textile fibres	279
95.3.1 General.....	279
95.3.2 Natural fibres	279
95.3.3 Chemical fibres.....	279
95.4 Yarns	280
95.4.1 General.....	280
95.4.2 Yarn types	281

95.4.3 Yarn notation	281
95.5 Yarn characteristics	281
95.5.1 General.....	281
95.5.2 Nomex and Kevlar	282
95.5.3 Insulative fibres.....	283
95.5.4 Yarn properties	285
95.6 Fabrics.....	285
95.6.1 Fabric definitions	285
95.6.2 Fabrics for flexible thermal insulation systems	286
95.7 Knitting and weaving techniques.....	286
95.7.1 General.....	286
95.7.2 Knitting	286
95.7.3 Weaving	287
95.7.4 Comparison of techniques	287
95.8 Textile component properties.....	287
95.8.1 General.....	287
iTeh STANDARD PREVIEW	
95.8.2 Thread parameters	287
95.8.3 Effects of temperature on textiles.....	288
95.9 Seam types.....	(standards.iteh.ai) 290
95.10 Procurement specification.....	290
95.10.1 General.....	290
https://standards.iteh.ai/catalog/standards/sist/1f0283ec-39cd-4819-990a-5de04bc287d1/sist-tp-cen-tr-17603-32-07-2022	291
95.10.2 Applicable standards and documents.....	291
95.10.3 Quality assurance	291
95.10.4 Deliverable documents.....	292
95.10.5 Delivery	292
95.10.6 Storage	292
95.11 References	293
95.11.1 General	293
96 Textile testing	294
96.1 Introduction.....	294
96.1.1 Textile industry testing	294
96.2 Loop tensile test	296
96.2.1 Test objective	296
96.2.2 Test set up.....	296
96.2.3 Specimen size	296
96.2.4 Test results	296
96.2.5 Success criteria	297