



SLOVENSKI STANDARD
SIST-TP CEN/TR 17603-32-21:2022
01-september-2022

Vesoljska tehnika - Priročnik za lepljenje

Space engineering - Adhesive bonding handbook

Raumfahrttechnik - Handbuch zu geklebten Verbindungen

iTeh STANDARD PREVIEW
Ingénierie spatiale - Manuel de collage
(standards.iteh.ai)

Ta slovenski standard je istoveten z: **CEN/TR 17603-32-21:2022**

[https://standards.iteh.ai/catalog/standards/sist/999ec84d-4261-4f89-b0e6-
ca1e66835c45/sist-tp-cen-tr-17603-32-21-2022](https://standards.iteh.ai/catalog/standards/sist/999ec84d-4261-4f89-b0e6-ca1e66835c45/sist-tp-cen-tr-17603-32-21-2022)

ICS:

49.025.50	Lepila	Adhesives
49.140	Vesoljski sistemi in operacije	Space systems and operations

SIST-TP CEN/TR 17603-32-21:2022 **en,fr,de**

TECHNICAL REPORT

CEN/TR 17603-32-21

RAPPORT TECHNIQUE

TECHNISCHER BERICHT

June 2022

ICS 49.025.50; 49.030.99; 49.140

English version

Space engineering - Adhesive bonding handbook

Ingénierie spatiale - Manuel de collage

Raumfahrttechnik - Handbuch zu geklebten
Verbindungen

This Technical Report was approved by CEN on 13 April 2022. 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.

iTeh STANDARD PREVIEW (standards.iteh.ai)

[SIST-TP CEN/TR 17603-32-21:2022](#)

[https://standards.iteh.ai/catalog/standards/sist/999ec84d-4261-4f89-b0e6-
ca1e66835c45/sist-tp-cen-tr-17603-32-21-2022](https://standards.iteh.ai/catalog/standards/sist/999ec84d-4261-4f89-b0e6-ca1e66835c45/sist-tp-cen-tr-17603-32-21-2022)



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

Table of contents

European Foreword.....	27
1 Scope.....	28
2 References	29
3 Terms, definitions and abbreviated terms.....	30
3.1 Terms from other documents	30
3.2 Terms specific to the present document'.....	30
3.3 References	48
4 Joining.....	49
4.1 Joining methods for space structures.....	49
4.1.1 General	49
4.1.2 Adhesive bonding	49
4.1.3 Mechanical fastening disadvantages.....	50
4.2 References	51
4.2.1 General	51
4.2.2 ECSS documents.....	52
5 Adherends.....	53
5.1 Introduction.....	53
5.1.1 General	53
5.1.2 Polymer composites.....	54
5.1.3 Metals	54
5.1.4 Ceramics.....	55
5.2 Advanced composites.....	56
5.2.1 Polymer-based composites	56
5.2.2 FML - Fibre metal laminates.....	60
5.2.3 MMC - Metal matrix composites	60
5.3 Metals.....	61
5.3.1 Structural materials	61
5.3.2 New materials	61
5.4 Higher-temperature applications	62

5.4.1	Adherends	62
5.4.2	Adhesives	62
5.4.3	General guidelines	64
5.5	Low-temperature and cryogenic applications	64
5.5.1	Adherends	64
5.5.2	Adhesives	64
5.5.3	General guidelines	65
5.6	Bonds between adherends	65
5.6.1	General	65
5.6.2	Composite-to-composite	65
5.6.3	Composite-to-metal.....	66
5.6.4	Metal-to-metal	66
5.6.5	Dissimilar materials	66
5.7	References	67
5.7.1	General	67
5.7.2	ECSS documents.....	68

6 Adhesive characteristics and properties..... 69

6.1	Introduction.....	69
6.1.1	General	69
6.1.2	Guidelines	69
6.2	Types of adhesives.....	70
6.2.1	Formulation.....	70
6.2.2	Characteristics	70
6.2.3	Mechanical properties	73
6.2.4	Environmental durability	73
6.2.5	Aerospace structural adhesives	74
6.3	Epoxy-based adhesives.....	74
6.3.1	General	74
6.3.2	Properties	75
6.3.3	Environmental durability	80
6.4	Polyimide-based adhesives	84
6.4.1	General	84
6.4.2	Properties	85
6.5	Bismaleimide-based adhesives.....	87
6.5.1	General	87
6.5.2	Properties	87
6.6	Silicone-based adhesives	89

CEN/TR 17603-32-21:2022 (E)

6.6.1	General	89
6.6.2	Properties	89
6.6.3	Environmental durability	91
6.7	Elastomeric adhesives	92
6.7.1	General	92
6.8	Adhesives used in space	92
6.8.1	Adhesive systems	92
6.9	References	96
6.9.1	General	96
6.9.2	Data sheets	97
6.9.3	Sources	98
6.9.4	ECSS documents	98
6.9.5	Other standards	98
7	Adhesive selection	99
7.1	Introduction	99
7.2	Adhesive selection factors	99
7.2.1	Guidelines	99
7.2.2	Evaluation exercise	99
7.2.3	Trade-off	100
7.3	Post application selection factors	101
7.3.1	Earth environment	101
7.3.2	Space environment	103
7.4	Pre-application selection factors	106
7.4.1	Joint design	106
7.4.2	Adhesive systems	106
7.4.3	Environmental factors	108
7.4.4	Cost factors	108
7.5	Application	109
7.5.1	Method	109
7.5.2	Cure factors	110
7.5.3	Health and safety	111
7.6	Adhesive screening criteria for space	112
7.7	References	113
7.7.1	General	113
7.7.2	ECSS documents	114
7.7.3	Other standards	115
8	Basic joint types	116

8.1	Introduction.....	116
8.2	Bond or mechanically fasten.....	116
8.2.1	General.....	116
8.2.2	Adhesive bonding in the space industry	118
8.3	Loading modes	118
8.4	Tensile shear loading.....	119
8.4.1	General.....	119
8.4.2	Joint geometry	120
8.4.3	Composite adherends	122
8.5	References	124
8.5.1	General.....	124
8.5.2	Sources.....	124
8.5.3	ECSS documents.....	125
9	Joint selection	126
9.1	Introduction.....	126
9.2	Joint strength.....	126
9.2.1	Failure modes	126
9.2.2	Guidelines	130
9.2.3	Joint design.....	131
9.3	Fatigue resistance	132
9.3.1	General	132
9.3.2	Joint evaluation	132
9.3.3	Factors influencing fatigue resistance	133
9.4	Acoustic fatigue resistance	135
9.4.1	Bonded carbon/epoxy composite joints	135
9.5	References	137
9.5.1	General	137
10	Theory and design practices	138
10.1	Introduction.....	138
10.1.1	Analysis	138
10.1.2	Factors of safety	138
10.2	Basic theories of bonded joints	138
10.2.1	Shear lag analysis.....	138
10.2.2	Linear-elastic stress-strain response.....	139
10.2.3	Non-linear stress-strain response.....	139
10.3	Environmental factors for bonded joints	144
10.3.1	Effect of temperature and moisture	144

CEN/TR 17603-32-21:2022 (E)

10.4 Effect of bonding defects	148
10.4.1 General	148
10.4.2 Description of bonding defects	148
10.4.3 NDT non-destructive techniques	156
10.5 Double lap and double strap joints	158
10.5.1 Stress distribution	158
10.6 Single lap joints	162
10.6.1 General	162
10.6.2 Load path eccentricity	162
10.6.3 Joint efficiencies	162
10.6.4 Adhesive characteristics	165
10.7 Double-sided stepped lap joints	165
10.7.1 Joint strength	165
10.7.2 Adherend stiffness balance	165
10.8 Single-sided stepped lap joints	168
10.8.1 Joint strength	168
10.9 Scarf joints	168
10.9.1 Joint strength	168
10.10 Calculation of bonded joint strength	169
10.11 Analysis of joint configurations	169
10.11.1 Analytical notation	169
10.11.2 Single lap shear joint	170
10.11.3 Double lap shear joint	173
10.11.4 Double-lap shear joint under mechanical and temperature loads	175
10.11.5 Single taper scarf joint	183
10.11.6 Double taper scarf joint	184
10.11.7 Stepped lap joint	185
10.11.8 Analysis of environmental factors	186
10.12 Analytical design tools	187
10.12.1 General	187
10.12.2 Commercial software	187
10.12.3 In-house software	187
10.13 ESAComp®	187
10.13.1 Background	187
10.13.2 Usage and scope	188
10.13.3 Analysis and data	188
10.14 ASTRUM: Example spreadsheet	191

10.14.1 General	191
10.14.2 Usage and scope	191
10.14.3 Analysis and data.....	191
10.15 ESDU data and software	194
10.15.1 General	194
10.15.2 ESDU 78042: Bonded joints - 1.....	194
10.15.3 ESDU 79016: Bonded joints – 2.....	195
10.15.4 ESDU 80011: Bonded joints – 3.....	196
10.15.5 ESDU 80039: Bonded joints – 4.....	196
10.15.6 ESDU 81022: Bonded joints – 5.....	197
10.16 Design chart	198
10.16.1 Aide memoire.....	198
10.16.2 Joint category.....	198
10.17 References	201
10.17.1 General	201
10.17.2 ECSS documents.....	203
10.17.3 Other standards	203
11 Design allowables	204
11.1 Introduction.....	204
11.2 Single lap joint	205
11.2.1 Static loading	205
11.2.2 Dynamic loading	209
11.3 Double lap joint.....	211
11.3.1 Static loading	211
11.4 Symmetrical double scarf joint	212
11.4.1 Static loading	212
11.4.2 Dynamic loading	214
11.5 References	216
11.5.1 General	216
11.5.2 ECSS documents.....	216
12 Surface preparation.....	217
12.1 Introduction.....	217
12.1.1 General	217
12.1.2 Standard processes	218
12.1.3 Development processes.....	219
12.1.4 Process steps	219
12.1.5 Legislation.....	219

CEN/TR 17603-32-21:2022 (E)

12.2 Composites: Thermosetting matrix	219
12.2.1 General	219
12.2.2 Techniques	220
12.2.3 Abrasion.....	220
12.2.4 Peel ply	222
12.3 Composites: Thermoplastic matrix.....	222
12.3.1 General	222
12.3.2 Proposed methods.....	223
12.4 Aluminium alloys.....	224
12.4.1 Aerospace aluminium alloys.....	224
12.4.2 MMC and Al-Lithium alloys.....	224
12.4.3 Optimised Forest Products Laboratory (FPL) etch.....	225
12.4.4 Phosphoric acid anodising (PAA)	227
12.4.5 Chromic acid anodising (CAA)	227
12.4.6 Boric sulphuric acid anodising (BSAA)	228
12.4.7 Thin film sulphuric acid anodising (TFSAA).....	231
12.4.8 Solvent vapour cleaning	231
12.4.9 Development processes.....	232
12.5 Titanium alloys.....	233
12.5.1 General	233
12.5.2 Acid or alkali etch.....	234
12.5.3 Non-chromium proprietary process	235
12.6 References	235
12.6.1 General	235
12.6.2 ECSS documents.....	237
13 Bonding methods	238
13.1 Introduction.....	238
13.1.1 Basic methods	238
13.1.2 Adhesives	238
13.1.3 Composite structures	239
13.2 Co-curing.....	240
13.2.1 Applications.....	240
13.2.2 Loading	242
13.2.3 Adhesives	242
13.2.4 Tooling	243
13.3 Secondary bonding.....	243
13.3.1 General	243

13.3.2 Adhesives	243
13.3.3 Tooling	244
13.4 Applying adhesives	244
13.4.1 Film adhesives	244
13.4.2 Paste adhesives.....	245
13.4.3 Manufacturing processes	248
13.5 Manufacturing factors for adhesives	249
13.5.1 General.....	249
13.5.2 Product-specific factors	249
13.6 Bondline integrity	251
13.6.1 General	251
13.6.2 Manufacturing-related factors.....	251
13.7 Thermal bonding thermoplastic composites	251
13.7.1 General	251
13.7.2 Direct bonding	252
13.7.3 Thermabond process	252
13.7.4 Welding techniques.....	253
13.8 Rapid adhesive bonding (RAB).....	253
13.8.1 General	253
13.8.2 Applications.....	253
13.8.3 Materials	253
13.8.4 Process	255
13.8.5 Equipment.....	255
13.8.6 Carbon fibre reinforced composites.....	256
13.8.7 Joint strength	257
13.9 References	257
13.9.1 General	257
13.9.2 ECSS documents.....	257
14 Quality assurance.....	258
14.1 Introduction.....	258
14.1.1 Documentation.....	258
14.1.2 Standards	258
14.1.3 Aerospace applications	258
14.2 Quality system	259
14.2.1 General	259
14.3 Specifications	259
14.3.1 Procurement	259

CEN/TR 17603-32-21:2022 (E)

14.3.2	Incoming inspection	260
14.3.3	Design.....	260
14.3.4	Processes	260
14.3.5	Materials	261
14.3.6	Training personnel	262
14.4	Check lists	262
14.4.1	Material procurement	262
14.4.2	Bonded joints	266
14.5	References	268
14.5.1	General	268
14.5.2	ECSS documents.....	268
15	Test methods	269
15.1	Introduction.....	269
15.1.1	Use of test methods	269
15.1.2	Adhesives for space use	269
15.1.3	Characterisation of adhesives	271
15.1.4	Assessment of adhesive bonding process	272
15.1.5	Test methods and standards.....	273
15.2	Tensile tests for adhesives	274
15.2.1	General	274
15.2.2	Adhesive evaluation.....	274
15.2.3	Sandwich panels: Flatwise tensile strength	275
15.3	Shear tests for adhesives	275
15.3.1	General	275
15.3.2	Napkin ring.....	275
15.3.3	Thick adherend single lap	276
15.3.4	Single lap	276
15.3.5	Double lap.....	278
15.3.6	Cracked lap shear (CLS).....	280
15.4	Cleavage of adhesives	281
15.4.1	General	281
15.4.2	Specimen geometry	281
15.4.3	Typical test results	284
15.4.4	Calculation of fracture strength.....	285
15.4.5	Loading	287
15.5	Bond durability by wedge test	287
15.5.1	General	287

15.5.2 Test specimen and configuration.....	287
15.5.3 Results and analysis	289
15.6 Peel tests.....	289
15.6.1 General	289
15.6.2 Climbing drum peel test for adhesives.....	290
15.6.3 T-peel test.....	291
15.6.4 Floating roller peel.....	291
15.7 Fatigue resistance	292
15.7.1 Fatigue properties of adhesives	292
15.7.2 Fatigue resistance of bonded joints.....	293
15.7.3 Acoustic fatigue.....	295
15.8 Creep resistance	295
15.8.1 Adhesive properties	295
15.8.2 Test methods	296
15.9 Environmental resistance.....	296
15.9.1 Earth	296
15.9.2 Space.....	296
15.10 References	297
15.10.1 General	297
15.10.2 ECSS documents.....	299
15.10.3 Other standards	299
16 Inspection.....	300
16.1 Introduction.....	300
16.2 Role of inspection	300
16.2.1 General	300
16.2.2 Quality control and inspection	300
16.2.3 Non-destructive testing	301
16.3 Defects	301
16.3.1 Bonded joints	301
16.3.2 Adhesion	301
16.3.3 Cohesive properties of adhesives	302
16.3.4 Significance of defects	302
16.4 Inspection techniques	304
16.4.1 Commonly-used techniques	304
16.4.2 Developments	305
16.5 Ultrasonic	306
16.5.1 Applications.....	306

CEN/TR 17603-32-21:2022 (E)

16.5.2 Limitations	306
16.5.3 C-scan	306
16.5.4 Leaky Lamb waves (LLW)	307
16.5.5 Acousto-ultrasonic	308
16.6 Radiography	308
16.6.1 Application	308
16.6.2 Limitations	308
16.6.3 X-radiography	309
16.7 Mechanical impedance: Bond testers	309
16.7.1 Application	309
16.7.2 Limitations	309
16.7.3 Principle	309
16.7.4 Fokker bond tester	310
16.7.5 Acoustic flaw detector	310
16.8 Holography	311
16.8.1 Application	311
16.8.2 Limitations	311
16.8.3 Principle	311
16.9 Thermography	311
16.9.1 Application	311
16.9.2 Limitations	311
16.9.3 Principle	312
16.10 Acoustic emission	312
16.10.1 Application	312
16.10.2 Limitations	312
16.10.3 Principle	313
16.11 References	313
16.11.1 General	313
16.11.2 ECSS documents	315
17 Materials for repairs	316
17.1 Introduction	316
17.1.1 General	316
17.1.2 Repair procedures	316
17.1.3 Repair levels	316
17.1.4 Basic features of bonded repairs	317
17.1.5 Objective of repair	317
17.1.6 Materials	317

17.1.7 Design.....	318
17.1.8 Quality assurance	318
17.2 Parent adherends	320
17.2.1 Materials	320
17.2.2 Sandwich structures.....	320
17.3 Repair patches	320
17.3.1 Materials	320
17.4 Adhesives.....	321
17.4.1 General.....	321
17.4.2 Structural	321
17.4.3 Splice	321
17.4.4 Fillers and mastics	322
17.4.5 Potting compounds	322
17.4.6 Properties	322
17.4.7 Repair adhesive selection factors.....	323
17.5 References	324
17.5.1 General.....	324
17.5.2 ECSS documents.....	325
18 Design of repairs	326
18.1 Introduction.....	326
18.1.1 Basic categories of repair.....	326
18.1.2 General design concepts.....	327
18.1.3 Composite repair design concepts	329
18.1.4 Sandwich panels, laminates and sheet metal.....	330
18.1.5 Cracked metal components.....	330
18.2 Concepts for laminates	330
18.2.1 General.....	330
18.2.2 Flush repairs	330
18.2.3 External repairs.....	331
18.3 Concepts for sandwich panels	331
18.3.1 Repair objectives	331
18.3.2 Field level repairs	332
18.4 Design parameters: Thin skin constructions.....	334
18.4.1 Design principles.....	334
18.5 Design parameters: Crack patching metals.....	336
18.5.1 Principles	336
18.6 References	337