ECSS-Q-ST-70-16C Adhesive bonding for spacecraft and launcher applications published

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17-02-2022

Motivation slide – upon kick off in 2016

Adhesive-related failures *	Probable suspects	Count	Sub-total	Total
Joint design	CTE mismatch & thermal expansion (design related)	3	7	55
	geometric effects (design related)	1		
	peel strength exceeded during handling (design & handling)	3		
Substrate related: selection, processing or performance	coating process (substrate)	1	4	
	corrosion related (substrate)	1		
	surface preparation (substrate)	1		
	incompatibility with cleaning agent (substrate)	1		
Contamination related & wrong cleaning procedures	**particulate contamination**	**2**	**9**	
	molecular contamination	**3**		
	unspecified contamination	**4**		
Adhesive processing and application failures	poor workmanship (application related)	3	8	
	adhesive mixing (processing & application)	3		
	poor curing (processing & application)	2		
Adhesive selection	adhesive selection	1	2	
	adhesive flow (adhesive selection)	1		
Environment (test & storage)	Overheating	3	6	
	incompatibility with UV/VUV	1		
	impact of ozone erosion	1		
	humidity	1		
Other failures	adhesive debris after failure (impact on others)	1	2	
	device related (mechanical loads)	1		
Programmatic failure	absence of sample-level testing pre- or qualification => delay	6	6	
Unknown or multiple causes	**under investigation when reported**	**11**	**11**	

* Only those reported by ESA's TEC-QT M&P engineers in years 2011-2015

Main content

- 1 scope
- 2 norm ref. (Q-ST-70, 70-71)
- 3 Definitions (e.g. test item, set, hot-wet testing vs. hot wet exposure…)
- 4 Principles –informative (design, performance, bonding process)
- **5 Selection of adhesive – Normative** (first hard requirements including already existing requirements from other standards, new requirements p21-23), + recommendations referring to Adhesive Bonding Handbook ECSS-E-HB-32-21
- **6 Definition of adhesive bonding process – Normative** (process requirements, bonding procedure, process traceability)
- **7 Verification of adhesive bonding - Normative** (test sequence, simulation of various influences on bonding, life cycle from first joint till end of mission, core of the standard)
- **8 Quality assurance - Normative** (extensive requirements and recommendations on bonders, inspectors, certifications, schools)
- Normative (A, B & C : bond. Procedure, Test plan, test report) and inform. Annexes (D, E, F and G)

“Scope” mentions what is not in the scope

This standard **does not** cover requirements for:

- Adhesive bonding used in EEE mounting on printed circuit boards (for this subject see ECSS-Q-ST-70-61)
- Adhesive bonding used in hybrid manufacturing (for this subject see ESCC 2566000)
- Adhesive bonding for cover-glass on solar cell assemblies (for this subject see ECSS-E-ST-20-08)
- Design of adhesive joints (for this subject see ECSS-E-ST-32)
- Long term storage and long term storage sample testing (specific guidelines are being developed)
- Performance of adhesive bonds
- Functional properties of adhesive joints
- Co-curing processes
- Life-time aging prediction, neither on ground (humidity) nor in-orbit (thermal cycling)

This standard may be tailored for the specific characteristics and constrains of a space project in conformance with ECSS-S-ST-00.

4 Principles (informative)

Handbook ECSS-E-HB-32-21 on one page

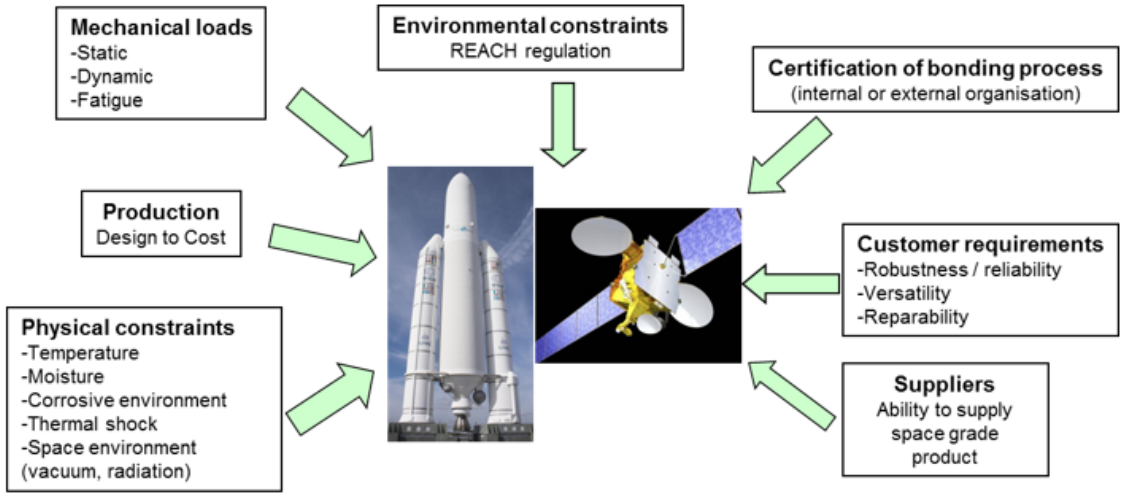
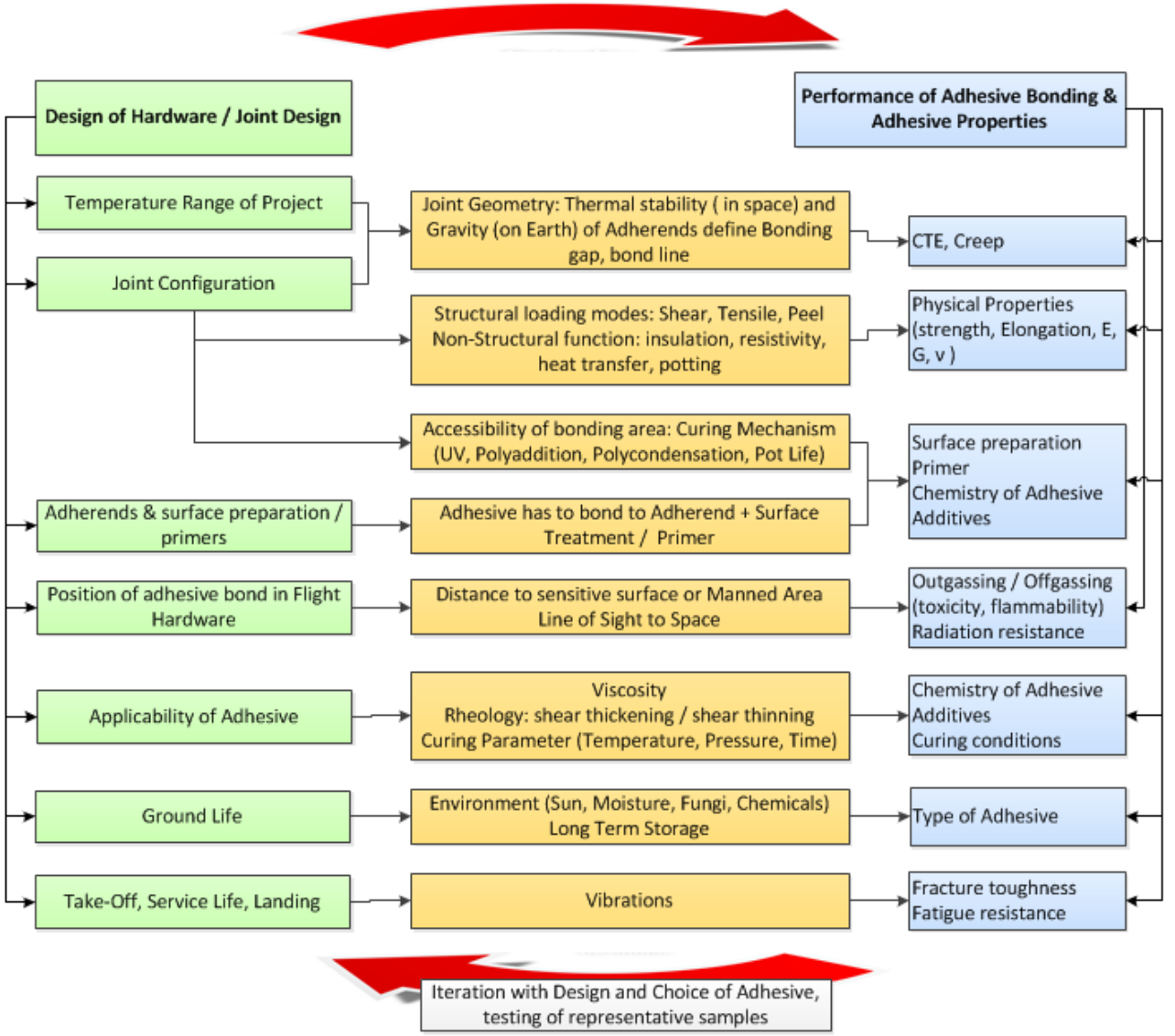


Figure 4-1: Overview of the constrains linked to adhesive bonds for space applications (not exhaustive)

To explain what the constrains are and what needs to be considered in design

No requirements here…

Design is iterative process



5 Selection of adhesive (normative)

- Quoting back ECSS-Q-ST-70s, 70-71c, 70-02 (except lower stages),
- Enveloping also parts from other material group requirements, in case adhesive is by definition one of them (thermoset, thermoplastic, elastomers)
- 5.2.f SHALL: Assessment of an application is basis for material selection (knowledge of service conditions of the joint since bonding till end of mission)
- 5.2.g Assessment SHOULD include…
  - Joint design, adhesive properties, processing, ground, launch, in-orbit…
  - Procurement, Health and Safety…
  - Adhesive properties SHOULD be analysed based on…. Annex D (Bulk) and Annex E (in-assembly)

6 Definition of adhesive bonding process

6.1 Adhesive bonding process requirements

6.1.a calling 70-71-4.3.2; 6.1.b: 70c clause 7, (already existing requirements)

Nothing new here except we **call for DRD Annex A - Adhesive bonding procedure**

6.1.d Conditioning

6.2: Adhesive bonding procedure,

- call for annex A DRD (deliverable)

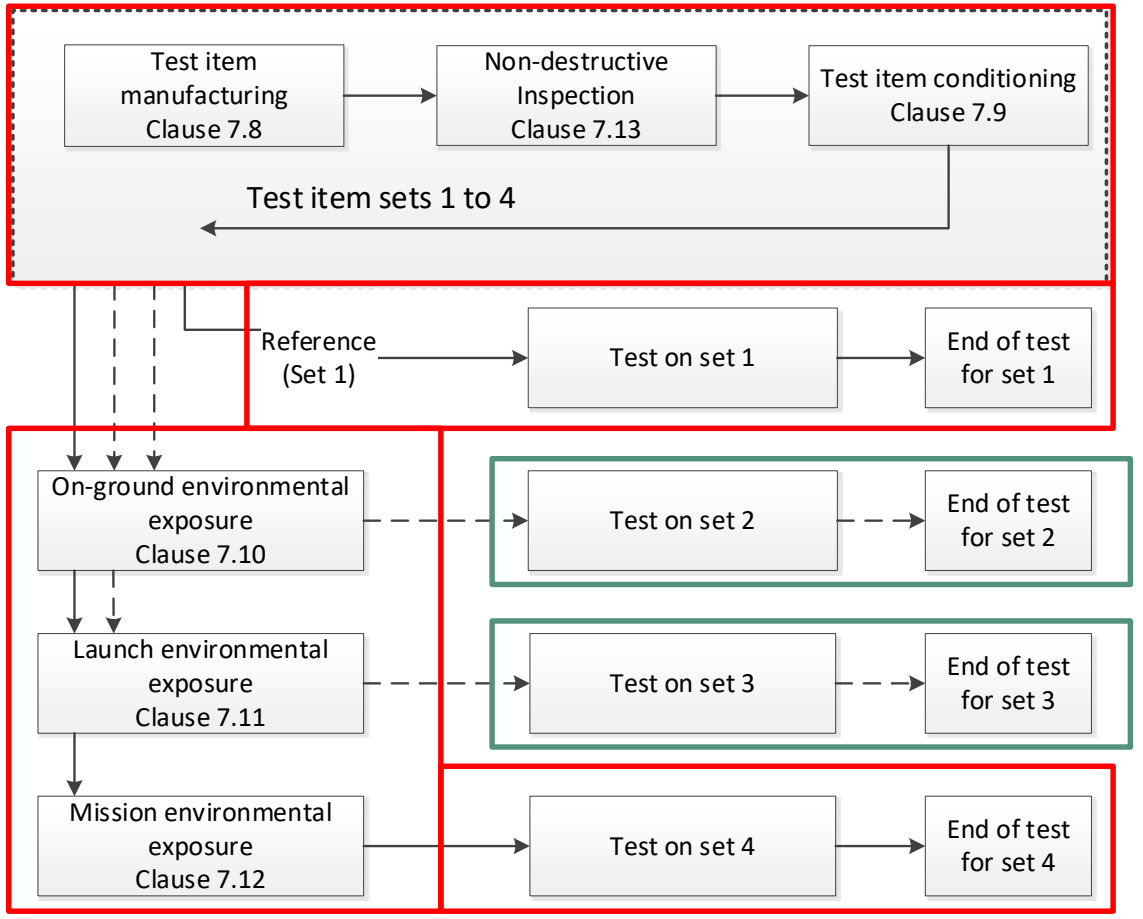
-Requirements on where do we refer to procedure (DPL there shall be reference)

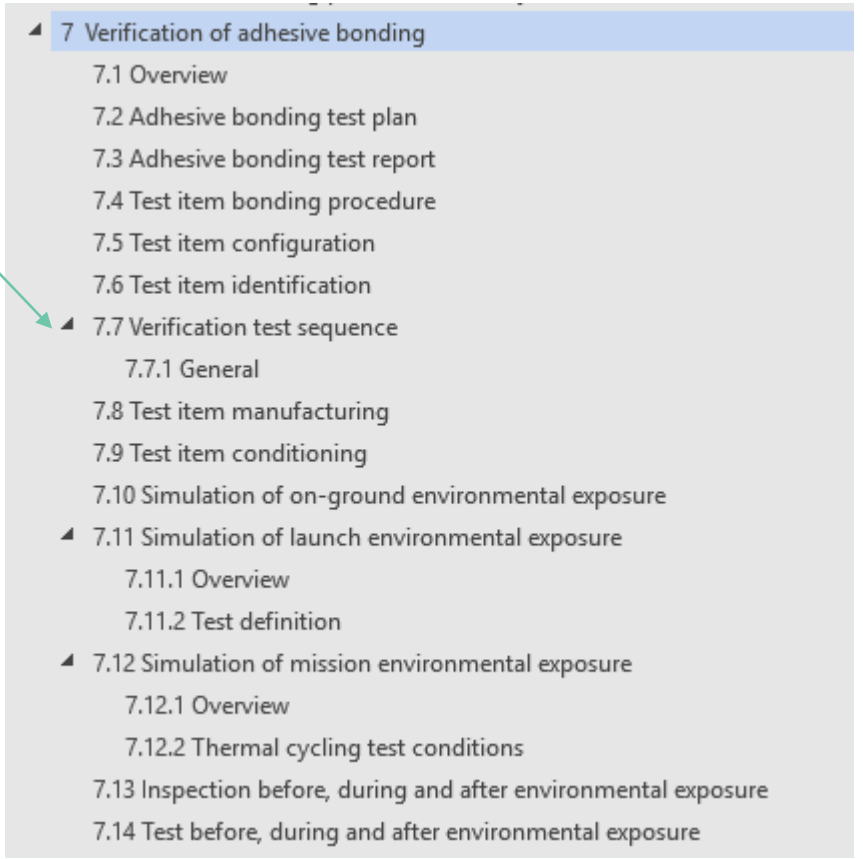
-Bonding process is executed according to this procedure!

6.3: Adhesive bonding traceability

- Set of minimum requirements, batch, operator, manufacturing files and so on

7 Verification test sequence





Compulsory vs. optional test streams

7.7 Verification of adhesive bonding

Quality assurance injection:

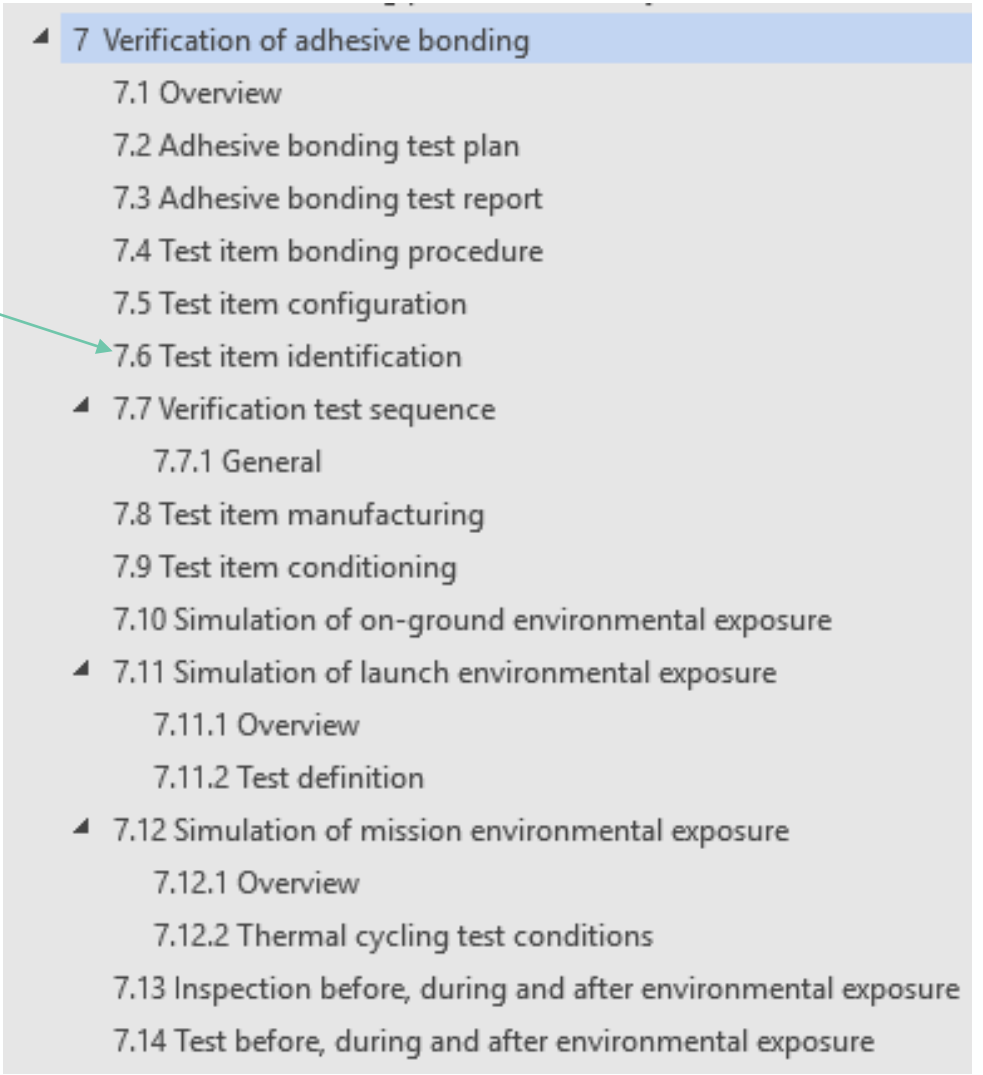
7.6 Test item identification

- Marking compulsory,
- List of details to be recorded and traced

7.7 Verification test sequence

7.7.1.a For the purpose of the verification test sequence the supplier shall identify the parameters affecting the performance of the adhesive bond within its life cycle.

= supplier is responsible to know under which conditions his joint is going operate (more accurate), this can avoid overtesting;



7 Verification test sequence

7.8 Test item manufacturing

- Minimum number: 5 test items per set (may be reduced – Customer approval)
- If the tests are for determination of Design allowables -> design authorities (whoever it is) shall reach agreement on number of samples (typically coming from statistical approach to be used) – **this decision cannot be made by M&P-level engineers! (can be 10, 20, 40 samples, Weibull, Normal dist., Log Norm…)**
- **We call ECSS-E-ST-32 Structural general requirements on the joints**
- Test items sets shall originate from the same test item population (Note: we don't tackle issue with delta qualifications and "post-mortem" or retrofit operations)

7.9 Test item conditioning

- a) Any conditioning step on F/HW to be performed on the test items, e.g. post-cure, burn-in, **bakeouts (T,p, time),** other types of conditioning…

7 Verification of adhesive bonding

7.10 Simulation of on-ground environmental exposure

a. The supplier shall demonstrate the robustness of the adhesive bonding in the relevant on-ground environment.

NOTE 1 Relevant on-ground environment is the environment representative of the exposure period between bonding and launch.

NOTE 2 Exposure to humidity or other chemical substances can contribute to the degradation of the adhesive bond.

b. On-ground robustness demonstration may be based on experience, adhesive bonding process heritage or test.

NOTE The term heritage is defined in Table 5-1 of ECSS-E-ST-10-02.

7 Verification od adhesive bonding

7.10 Simulation of on-ground environmental exposure

- c) for Launcher apps is the hot-wet exposure "**shall"** (no issue here as those cover outdoor applications and uncontrolled environment exposures)
- **Spacecrafts "shall" on following:**
- **d)** For spacecraft applications the sensitivity to atmospheric humidity shall be assessed
- **e)** For spacecraft applications exposed to cleanroom-controlled environments the hot-wet exposure need not to be always performed

WHAT? Aren't these two (d and e) contradicting? How do we decide?

There is way out based on criticality/sensitivity matrix described in Annex F, tables F-1 (criticality of adhesive bonding application), F-2 (sensitivity to on-ground environment), F-3 (decision matrix)

7.11 Simulation of Launch environmental exposure

- To be agreed with Customer, -> we call for System level requirements
- Allow combination of thermal loads from launch with thermal loads from mission (Section 7.12)
- Description of mech. loading types (no dynamic tests for standard mech. test samples),
- Complemented by 7.14 for mechanical type of test items (more like standard adhesive joint test samples)
- For more complicated assemblies it is actually realistic test flow, with first on-ground, then launch, then mission environment with e.g. functionality test before and in the end (Set 1 vs. Set 4, or BOT vs. EOT)

7.12 Simulation of mission environmental exposure

- mainly refers to TVC, special cases traced under special Test flow (in addition to 3 exposure steps, we call for ECSS-Q-ST-70-06 and other types of exposures)
- 7.12.2 Thermal cycling test conditions

a) Shall be agreed with customer; Noting ECSS-Q-ST-70-04 for guideline

b) Minimum 25 cycles (to cover ground testing, not whole mission!)

c) …shall avoid water condensation in ambient pressure cycling

d) Minimum 5 cycles shall be performed in TVC for vacuum sensitive configurations,

List (not exhaustive): Adhesive tapes, Foil heaters, Thin or flexible adherends, Radiator foils, Solar reflectors

- Any assembly crossing Tg temperature of its adhesive material during the thermal cycling
- Assemblies for which moisture desorption has an impact on the bonding performance (CME effect)

7.12 Simulation of mission environ.. cont. 2

f. In addition to requirement 7.12.2b additional thermal cycles shall be performed to cover mission lifetime.

NOTE 1 The additional thermal cycles are typically performed to simulate ageing effects (thermo-chemical, creep and fatigue phenomena).

NOTE 2 The additional thermal cycles can contain long term thermal endurance exposure, for example cruise phases of probes.

g. For thermal vacuum cycles, the pressure level shall be less than 1 Pa (10^{-2} mbar).

These two requirements should assure affordable testing, with lest constrains on test setups (low vacuum) putting emphasis on more cycles

7.13 Inspections

- Covered in Chapter 8 in detail

7.14 Test before, during and after environmental exposure

a. Test of test item set shall be performed according to adhesive bonding test plan specified in the 7.2

+ notes on features of the tests in additions, e.g. IR monitoring and so on

b. For mechanical test samples static performance test shall be performed at least for test item sets 1 and 4.

NOTE Examples of standard mechanical tests are given in Annex E

8 Quality assurance

8 Quality assurance 39

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8.8 Workmanship 42
8.9 Handling and storage 43
8.10 Inspection and bonding process control 45
8.11 Operator and inspector training 46
8.12 Nonconformance 47

Good for process control and audits, NCR investigations…

There is a lot of new requirements on procurement, incoming, workmanship, training, certification, NDI

(in total @ 53 requirements and recommendations

reference to informative Annex G with list of bonding schools, European certification scheme. etc..

Normative annexes

Annex A (normative)
Adhesive bonding procedure – DRD

Annex B (normative)
Adhesive bonding test plan - DRD

Annex C (normative)
Adhesive bonding test report -DRD

Formal content (deliverables)

Informative annexes

Annex D (informative)
Examples of techniques used for adhesive material characterization (bulk)

Annex E (informative)
Characterisation of adhesive in bonded assembly configuration

Annex F (informative)
Effects of the ageing on adhesively bonded joints

Annex G (informative)
System for training and qualification of adhesive bonding personnel

Informal part (best practice)

Examples of criticality of the joint vs. sensitivity to environment

Table F-1Example of the classification of adhesive bonding process in spacecraft and launcher applications based on its criticality

Criticality	Definition and examples
Highly critical	Any adhesive joint, failure of which can lead to loss of mission, loss of spacecraft or loss of crew. Examples: Structural adhesive bonding with high dimensional stability or strength requirements on the joint (for example bonding of optical elements as lenses, mirrors). Structural adhesive bonding with high mechanical and static loads applied during on-ground, pre-launch, launch or mission phase. Primary structure joints without any redundancy (no extra riveting, bolts nor any other mechanical back up). Bonding of thermal protection systems (TPS) exposed to high thermal fluxes during on-ground, pre-launch, launch, mission, atmospheric entry or re-entry phase, facing significant mechanical or thermo-mechanical loads at the same time.
Critical	Any adhesive joint, failure of which can lead to significant damage of the spacecraft or degradation of the mission or injury of crew members. Examples: Primary structure joint with redundancy (bolted, secured with rivets). Secondary structure joint (for example bonding of stand-offs for MLI). Non-structural or semi-structural joints with other specific function (for example bonding of radiation shielding for electronics, shielding of crew capsule or both; electrically conductive bond.
Not critical	Any adhesive joint, failure of which has no adverse effect on the spacecraft or on the mission and cannot cause injury of crew members. Examples: Bonding of cable-tie bases with significant number of redundant measures (for example sensors, cable bundle potting or encapsulations). PSA tape marking, cable wrapping. Non-structural joints (e.g. without any other function than in place holding, marking etc.).

Table F-2: Examples of adhesive bonding applications and their sensitivity to on-ground humidity exposure (based on their failure occurrence)

Sensitivity	Definition and examples
Highly sensitive	Performance of the key property is reduced by more than 35% after exposure to moisture with respect to reference value Examples: Bonding to surfaces exposed to uncontrolled environments, where molecular or particle contamination, humidity or temperature is not controlled. Bonded assembly with very small overlap areas where diffusion rate of water trough adhesive/adherend interface layer is high or not prevented by design. Bonding of optical glasses, mirrors (fused silica,) or any similar adherend sensitive to moisture (for example CaF2, MgF2, lithium-aluminosilicate glass-ceramic). Bonding of adherend materials known to show signs of surface degradation already in ambient environments, (55 ±10) % RH and (22 ± 3) °C, for example low Fe-Ni alloys, low Cr-alloyed steels, carbon steels. Bonding with 2-c epoxy adhesive with Tg close to RT without option of post-cure process at elevated temperatures before exposure to on-ground environments, including controlled environments in clean rooms at (55 ±10) % RH and (22 ± 3) °C. Bonding to metallic surfaces with insufficient surface treatment (where proper surface treatment is prevented by application, for example AIT, repair on spot). Bonding with adhesive materials which are known to be moisture-sensitive when they are in their cured state.
Sensitive	Performance of the key property is reduced significantly (between 35 % and 10 %) after exposure to moisture with respect to reference value. Examples: Adhesive bonding applications with insufficient surface treatment of metallic adherends (absence of chemical etching, pickling, anodising processes). Adhesive bonding applications without stabilisation of adherend-adhesive interface (for example without use of primers, silanization by other techniques such as pyrolysis). Bonding on thermo-optical coating layers or painted substrates without removal of paint or coating. Bonding to primed areas with longer exposures to humidity between priming and adhesive application.
Insensitive	Performance of the key property is not affected after exposure to moisture (less than 10 % reduction) with respect to reference value. Examples: The key property of the adhesive material in cured state is not sensitive to moisture. Bonded assembly with large overlapping areas limiting access to ambient humidity to the centre of overlap where diffusion rate of water through adhesive/adherend interface layer is limited. Bonding to metallic surfaces which have enhanced endurance by corrosion inhibiting primers or similar protection systems.

Annex F: To be or not to be… hot-wet exposed?

Sensitivity to moisture vs. criticality of the joint

Table F-3: Example table with assessment for implementation of hot-wet exposure into the verification sequence (step: simulation of on-ground exposure)

		Sensitivity of the adhesive bond to moisture		
		Highly sensitive	Sensitive	Non-sensitive
Criticality of the bonding process application	Highly critical	Yes	Yes	Yes ?
	Critical	Yes	Yes ?	No
	Non-critical	Yes ?	No	No

NOTE: Yes: hot-wet exposure is recommended to be performed, No: hot-wet exposure need not to be performed

I want to apply adhesive bonding technology…
… how do I start?

PQ/QA approach?
ECSS-Q-ST-70-16c

ECSS-Q-ST-70-16C DIR2
28 May 2018

EUROPEAN COOPERATION FOR SPACE STANDARDIZATION

Space product assurance

Adhesive bonding for spacecraft and launcher applications

This draft is circulated to the ECSS community for Public Review.
(Duration: 8 weeks)
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End of Parallel Assessment: 23 July 2018

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86 pages

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

Engineering approach?
ECSS-E-HB-32-21A

ECSS-E-HB-32-21A
20 March 2011

EUROPEAN COOPERATION FOR SPACE STANDARDIZATION

Space engineering

Adhesive bonding handbook

461 pages

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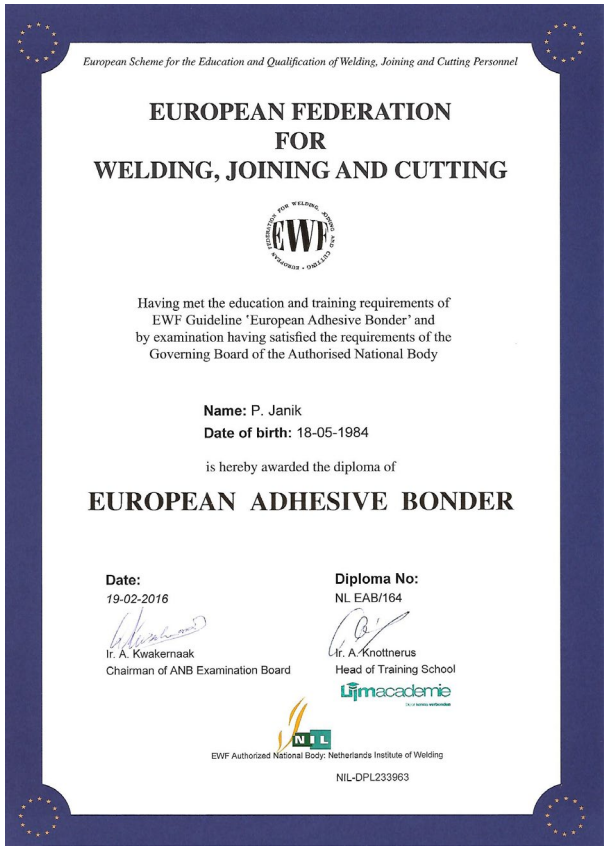
Hands-on approach?
EAB, EAS, EAE courses



DIN 2304/ DIN 6701-2
Quality assurance for the whole bonding process (40-332h)

Training and certification, EAB scheme

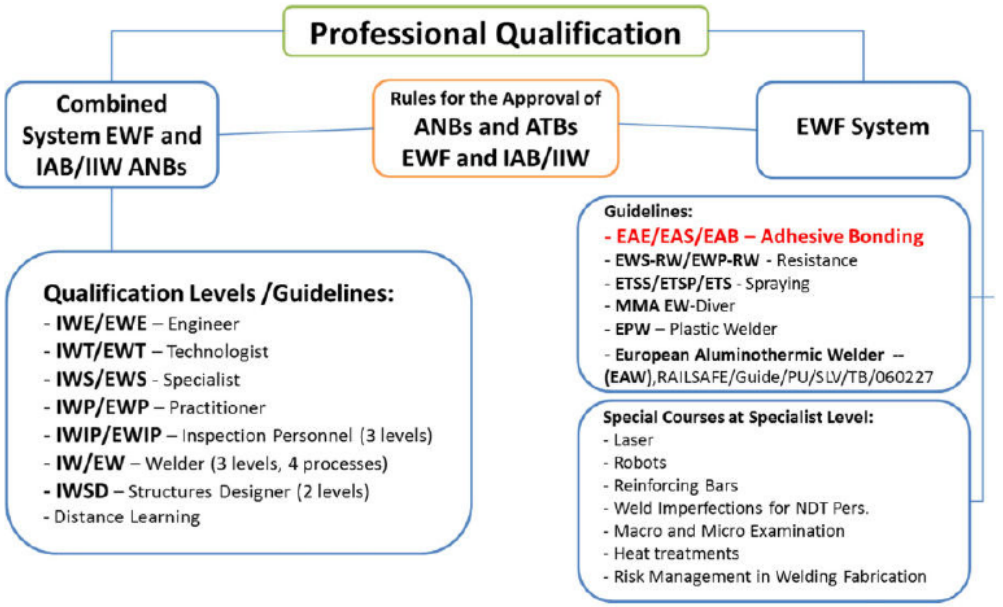


Figure G-1: The International Training and Qualification system for Personnel [Quintino L. et al.]

Entities providing training for adhesive bonding are listed below. The training is structured in three levels:

- European Adhesive Bonder (EAB), DVS® / EWF 3305 and EWF 515
- European Adhesive Specialist (EAS), DVS® / EWF 3301 and EWF 516
- European Adhesive Engineer (EAE), DVS® / EWF 3309 and EWF 517

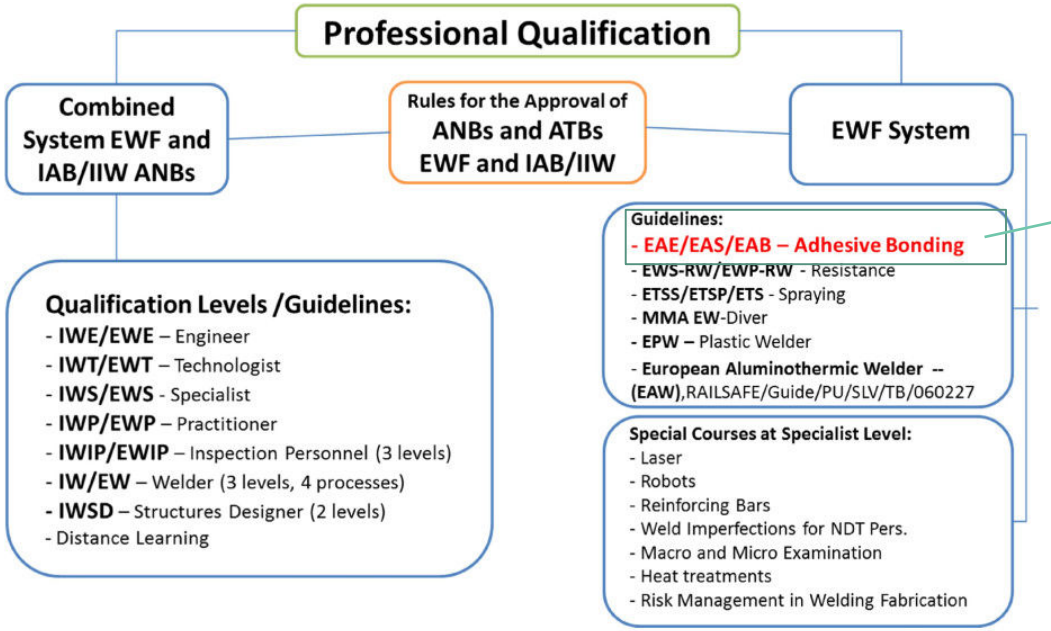
Table G-1: The list of entities eligible to provide training for adhesive bonding*

Country	School	Contact details
Austria	OFI GmbH	OFI Technologie & Innovation GmbH, Franz-Grill-Straße 5, Objekt 213, 1030 Wien http://www.ofi.at/
Belgium	TECHNIFUTUR	Technifutur® asbl, Liège Science Park, Rue Bois Saint-Jean 15-17, B-4102 – Seraing http://www.technifutur.be/catalogue-des-formations-assemblage
Czech Republic	Centrum Lepení Brno	Centrum Lepení Brno, SVV Praha, s.r.o., Vídeňská 55, 639 00 Brno http://svv.cz/adhesive-bonding
France	Rescoll	Rescoll, 8 Allée Geoffroy Saint-Hilaire, 33600 Pessac https://rescoll.fr/rescoll/
Germany	IFAM	Fraunhofer-Institut für Fertigungstechnik und Angewandte Materialforschung IFAM, Wiener Straße 12, 28359 Bremen https://www.ifam.fraunhofer.de
Germany	TC Kleben GmbH	TC-Kleben GmbH, Carlstraße 50, 52531 Übach-Palenberg http://www.tc-kleben.de
Germany	SKZ Halle	Frankfurter Str. 15-17, 97082 Würzburg http://www.skz.de/
Italy	Istituto Italiano della Saldatura	Istituto Italiano della Saldatura, SEDE CENTRALE DI GENOVA, Lungobisagno Istria, 15A, 16141, Genova https://www.iis.it/
Netherlands	Adhesive Bonding Center	Adhesive Bonding Center, Vaartweg 81E, 8243 PD Lelystad http://adhesivebondingcenter.nl
Netherlands	Lijmacademie B.V. / IFAM	Lijmacademie B.V., Ericssonstraat 2, 5121 ML Rijen http://www.lijmacademie.eu
Poland	Instytut Spawalnictwa	Instytut Spawalnictwa, ul. Błogosławionego Czesława 16-18, 44-100 GLIWICE http://is.gliwice.pl/
Spain	CESOL	CESOL, C/ Condado de Treviño, nº 2 – Local F31, 28033 Madrid www.cesol.es
Spain	ITCS	ITCS - Ctra. de Molins de Rei a Sabadell, 79, Nau 8 bis NUEVO 08191 Rubí, Barcelona http://www.itcsoldadura.org/

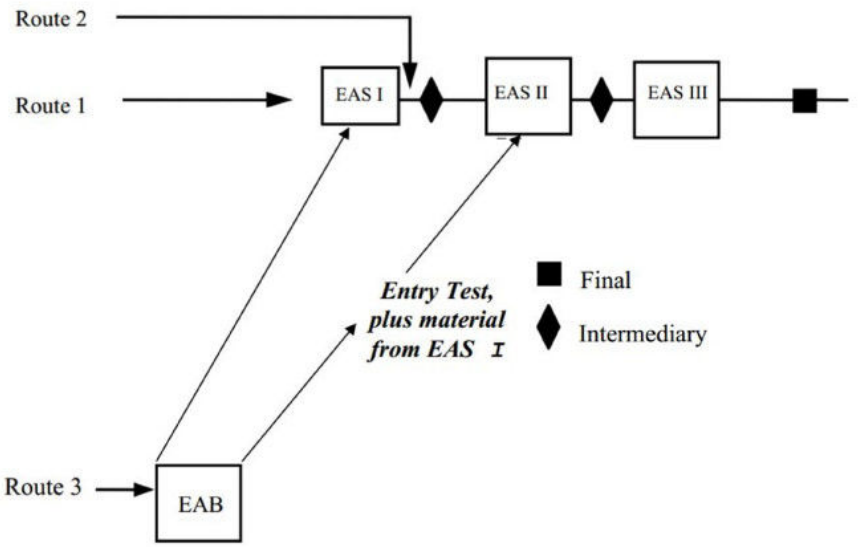
NOTE: * The list in the table is not exhaustive and can change over time. Quoted entities often organise trainings also in other countries in collaboration with local universities or training institutes. For actual list of all Authorised Training Bodies (ATBs) consult your local Authorised National Body (ANB) or European Federation for Welding, Joining and Cutting (EWF).

European Adhesive Bonding training scheme

- adopting the philosophy of EWF training for welders



The international Training and Qualification system for Personnel [1]



Routes for the diploma European Adhesive Specialist[2]

0 —40h+EAB exam→ EAB (bonder) —0+120h+EAS exam / EAB+80h+EAS exam→ EAS (specialist) —332h+EAE exam→ EAE (engineer)

[1] Quintino L, Ferraz R, Fernandes I: International education qualification and certification systems in welding. Welding World 2008, 52: 1.
[2] Quintino et al.: European harmonised system for training and qualification of adhesive bonding personnel. Applied Adhesion Science 2013 1:2., https://doi.org/10.1186/2196-4351-1-2

M&P's awareness of this standard

- In line with already existing requirements from Q-ST-70 and Q-ST-70-71
- Detailed content of bonding procedure, test plan and test report (new)
- Minimum test sequence (2x5 samples, reference and cumulative set), ground, launch & mission environment,
- If design is in the subject of verification (not only material and process) design authority is responsible for agreements on success criteria, number of samples… not only M&P alone (not in this standard!),
- Pressure and number of TVC and overall thermal cycles relaxed to enable everyone to run verification and to get results fast (less expensive), cost effective,
- Tough requirement on Mission life time test for thermal cycles and other constrains (project responsibility),
- Exemplar decision matrix for hot-wet exposure for Spacecraft applications, suggested exposure types and exposure conditions in Annex F (some theory behind),
- **Requirements in Chapter 8 – Quality assurance are dedicated to adhesive bonding processes, incoming inspections, workmanship, training, traceability and so on…**

Conclusions

- Wide scope of ECSS -> large WG (all primes represented) -> has advantages as well as disadvantages (spacecraft & launchers = some divergence, which needed to be reflected in separate requirements),
- 132 requirements and recommendations,
- Unique requirements on adhesive bonding process, focusing on workmanship, traceability and process control (should help to simplify MPCB process, defining verification sequence),
- New PA/QA requirements should minimise the “obvious” failures
- The approach is already used in frame of MPCBs/RFAs of currently running ESA projects

Feedback:

Even though the standard is new and should be mature enough reflecting state of the art approach for adhesive bonding verification, any further feedback is always appreciated!

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