



BSI Standards Publication

Railway applications — Adhesive bonding of rail vehicles and their components

National foreword

This British Standard is the UK implementation of [EN 17460:2022](#).

The UK participation in its preparation was entrusted to Technical Committee RAE/3, Railway Applications - Rolling Stock Products.

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

BSI, as a member of CEN, is obliged to publish EN 17460 as a British Standard (or Published Document). However, attention is drawn to the fact that during the development of this European Standard (or Technical Specification), the UK committee voted against its approval.

The UK committee voted against the adoption of the standard for reasons relating to the details of the standard's rABC certification method and the lack of guidance to potentially useful external sources of information.

The committee feels that the method of certifying an rABC with only a two- to three-week class – and without requiring any previous qualifications or experience to design, qualify, implement, or accept signatory authorization authority for, all bonded joints on a passenger rail vehicle – is inadequate (particularly in light of the fact that the rABC role can be held without mandatory practical training or experience).

The UK committee therefore suggests that users of this standard also follow PD ISO/TS 22163, *Railway applications — Quality management system — Business management system requirements for rail organizations: ISO 9001:2015 and particular requirements for application in the rail sector*, to ensure tasks and activities related to adhesive bonding and sealing meet the requirements of IRIS Guideline 6.

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de véhicules et de pièces ferroviaires

Bahnanwendungen - Kleben von
Eisenbahnfahrzeugen und deren Teilen

This European Standard was approved by CEN on 22 May 2022.

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European foreword

This document ([EN 17460:2022](#)) has been prepared by Technical Committee CEN/TC 256 “Railway applications”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by January 2023, and conflicting national standards shall be withdrawn at the latest by January 2027.

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Introduction

Historically, the production of railway vehicles and their components, for the main part, comprises such materials as steels and aluminium alloys. Their methods of construction and assembly include such processes as bolting, riveting, and welding.

Railway vehicles within the meaning of this document are defined in [EN 15380-1](#) [47].

Technological developments have led to the availability of other materials, e.g. composites, and some of these traditional methods of construction as bolting, riveting, and welding and assembly are not necessarily appropriate or suitable for such materials.

For this reason, a process of adhesive bonding can be essential for the production of certain railway vehicles and their components, not only in the case of composites but for steels and aluminium alloys as well as glass and other materials.

The confirmation of the quality and integrity of the final adhesively bonded joints do not readily lend themselves to traditional inspection and testing techniques such as non-destructive testing.

Therefore, it is essential that the quality and control of the adhesively bonded joints of assemblies and components is managed to the best possible level by means of an appropriate process control procedure.

Whilst there are standards that deal with Quality Control and are taken into account, this document aims to give the correct framework and includes additional detail necessary for all adhesive bonding and sealing activities performed on railway vehicles and its components as a special process.

NOTE EN ISO 9001 [41] is such an example.

Against this background, this document refers to definitions as well as organisational, management, contractual and technical principles to be followed in production of adhesively bonded joints in analogy to welding technology. Thus, comparable focal points are also the focus here:

Focal point 1: Classification of each adhesively bonded joint according to safety requirements (see [5.3.2](#)).

Focal point 2: Designation of supervisory personnel (Adhesive Bonding Coordinators - ABCs) and execution personnel (Adhesive Bonding Operators) who can objectively demonstrate that they have the necessary and required skills, knowledge, and experience in the field of adhesive bonding (see [Clause 4](#)).

Focal point 3: Verification that the actual loading (stress, strain, and strain energy) of an adhesively bonded joint during the use of an adhesively bonded product is in any case less than the maximum load capacity (see [5.4](#) and [Annex D](#)).

Another focus of this document are the principles of workmanship of adhesively bonded joints (see [Clause 6](#)).

1 Scope

This document defines terms and specifies requirements for adhesive bonding and sealing work in rail vehicles and their components independent of the material of the adherend and the solidification mechanism, strength, and deformation properties of the adhesives.

This document is applicable to adhesive bonding and sealing adherends in the:

- development (pre-production);
- production (in-production);
- maintenance including repair (post-production);
- quality assurance of production, inspection, maintenance including repair of rail vehicles and their components.

This document is not applicable to:

- screw retention by the usage of adhesives, if a screw assembly without further safeguard of identical joint design is sufficient for the purpose;
- hybrid joints, if the expected function is given exclusively by another joining technology e.g. welding, screwing, riveting;
- production of vulcanizates;
- production of plywood;
- production of fibre reinforced plastic composites (FRP-composites);
- production of laminated safety glass;
- pure encapsulating of electronic parts;
- application of single-sided adhesive decorative films.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

[EN 1465](#), *Adhesives — Determination of tensile lap-shear strength of bonded assemblies*

[EN 923](#), *Adhesives — Terms and definitions*

[EN ISO 10365](#), *Adhesives — Designation of main failure patterns*

[ISO 16269-6:2014](#), *Statistical interpretation of data — Part 6: Determination of statistical tolerance intervals*

[EN 14869-2](#), *Structural adhesives — Determination of shear behaviour of structural bonds — Part 2: Thick adherends shear test (ISO 11003-2)*

[ISO 12107](#), *Metallic materials — Fatigue testing — Statistical planning and analysis of data*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in [EN 923](#), and the following apply.

NOTE An additional clarification of vocabulary associated with adhesive bonding technology is given in [Annex I](#).

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1

adhesion

technical term for the interactions between the adhesive polymers and the adherend/substrate surface

NOTE Adhesion occurs in nm-dimensions.

3.2

cohesion

internal strength of a material, e.g. an adhesive

NOTE Cohesion forces keep for example the molecules of an adhesive together and are based on attractive physical forces between the polymer chains, entanglement of the polymer chains, and chemical bonds inside and between the adhesive polymer chains.

3.3

adhesive

non-metallic material which bonds two adherends/substrates together via adhesion and cohesion

3.4

adherend

substrate

object or semi-finished product (e.g., sheet metal, wires, metal extruded, moulded plastic, fabrics, glass, coated substrate, etc.) on which an adhesive is applied

NOTE In adhesive bonding processes, the term adherend is often used as a synonym for substrate.

3.5

adhesion promotor

liquid used in surface treatment to improve the adhesion of the adhesive to the adherend

NOTE Adhesion promotors often are named as primers, accelerators, or activators (see also [I.2.2](#)).

3.6

adhesive bonding

process of joining together the adherends by an adhesive or sealant

NOTE The adherends/substrates can be made of the same as well as of different materials and can have different surface characteristics.

3.7

adhesive bonding area

area which is used to join one or more adherends/substrates using an adhesive

NOTE The adhesive bonding area is usually the product of the overlap length and overlap width of the adherends/substrates.

3.8 **Adhesive Bonding Coordinator** **ABC**

qualified person with proven expertise in adhesive bonding technology responsible for the supervision of the adhesive bonding processes and for all linked activities

NOTE The responsibilities of the Adhesive Bonding Coordinators (ABCs) are shown in [Table 1](#).

3.9 **responsible Adhesive Bonding Coordinator/deputy** **rABC/d**

qualified person with level of competence according to [Table 1](#) in adhesive bonding technology to supervise the full scope or a part of the full scope as the highest instance regarding bonding technology including announcements of deputies according to scope and class

3.10 **adhesive bonder**

personnel with proven corresponding knowledge applying or executing the adhesive bonding process to manufacture, maintain, or repair components

3.11 **adhesive bonding personnel**

personnel involved in the design, planning, manufacturing, and maintenance/repair related to the adhesive bonding process

3.12 **adhesive bonding procedure**

all associated processes concerned with adhesive bonding such as conditioning of substrates and adhesive, surface treatment, processing the adhesive, application of the adhesive, joining the adherends/substrates and solidification (curing/hardening)

3.13 **adhesively bonded joint**

connection of two or more substrates (adherends) from the same material or different materials with the use of an adhesive

NOTE An adhesively bonded joint can be defined as rigid coupling, flexible coupling, or joint sealing. All three types of junction are based on the same principles of operation.

3.14 **structural adhesively bonded joint**

adhesively bonded joint in which the adhesive bond makes a significant contribution to guarantee the load-transferring between the adherends

3.15 **component**

one part of an adhesive

NOTE In adhesive bonding technology, the parts of an adhesive system (resin and hardener) are called components (component A and component B).

3.16 **ageing**

changes in adhesively bonded joints and their properties over time

Note 1 to entry: Ageing can be simulated by storage of laboratory test samples under special climatic conditions in order to mimic, over a short period of time, the effects to which adhesives/adhesively bonded joints are exposed during their whole real lifetime.

Note 2 to entry: Adhesives can age due to the effect of moisture, chemicals, oxygen, heat, light, mechanical stress, etc.

3.17

application

place adhesive on an adherend during the adhesive bonding procedure

3.18

curing

chemical solidification of the adhesive

chemical reactions leading to adhesive solidification (thermoplastic, elastomeric, or thermoset polymers)

NOTE This refers to chemically curing adhesives.

3.19

curing time

period of time required to solidify a chemically curing adhesive until final strength

3.20

technical data sheet

technical information sheet about an adhesive written by the adhesive manufacturer

NOTE It gives information about the adhesive and how to process and apply the adhesive (also called: TDS).

3.21

safety data sheet

information sheet about product-related important safety instructions Note 1 to entry: Also called Material Safety Data Sheet (MSDS).

3.22

destructive testing

analyses, tests, or surveys carried out on a test sample or system for getting qualitative/quantitative specific properties

NOTE The test sample cannot be used afterwards.

3.23

non-destructive testing

NDT

analyses, tests, and measurements performed using methods which do not unduly alter the material and do not damage or destroy the sample in the test system, aimed at the investigation and identification of defects of the structure itself

NOTE Each test sample can be used afterwards without compromising the functioning of the product.

3.24

handling time

time which is reached when the solidification of the adhesive in the adhesively bonded joint has progressed to such an extent that - without impairing the quality of the respective adhesively bonded joint in any way - the next work step including the resulting loading can be initiated, the rail vehicle or rail vehicle part can be delivered or its commissioning can take place

3.25

hot spot

FEM

small region or area with a high value of a quantity (e.g., stress, strain, energy)

3.26

influence

non-mechanical parameters that are applied to a material and change its properties

NOTE The nature of the non-mechanical parameters influences the material behaviour (loading) and the load capacity to be selected. Further influences can have an impact of the adhesive selection.

3.27

joining

assembling of substrates/adherends ([3.1](#)) to become a whole

NOTE Adhesive bonding is just one joining method. Others are welding, screwing, and riveting.

3.28

load

mechanical parameters that are applied to a material and lead to stresses and strains (deformations) in the material

NOTE The type of mechanical parameters influences the material behaviour (loading) and the load capacity (see [3.29](#)) to be selected.

3.29

load capacity

limit of the adhesively bonded joint to withstand stress, strain and strain energy

3.30

load case

combinations of loads and influences applied to an adhesively bonded joint at the same time

NOTE Usually there are several load cases which describe different states in vehicle operation as well as in the manufacturing/repair process. Manufacturing/repair load cases are always to be evaluated in combination with the solidification state of the adhesive and are the basis for the determination of handling strength or commissioning times.

3.31

non-mechanical load

different types of external influences, which can act on an adhesively bonded joint, e.g. heat, moisture, and chemical effects (water, solvents, etc.)

3.32

mechanical property

property related to the behaviour of an adhesive or adhesively bonded joint when subjected to external physical forces (tensile forces, shear forces, abrasive forces, compressive forces, torque, lap shear forces, etc.)

3.33

pot life

period of time in which a reactive 2C adhesive shall be applied after putting together and mixing its components until the maximum permissible viscosity for still sufficient wetting is reached (the maximum processing time)

Note 1 to entry: This time depends on the speed and the rate of the chemical reactions responsible for the polymer formation (curing rate) and also on the external boundary conditions (e.g. temperature, quantity of mixture prepared). In order to create high-quality adhesively bonded joints the pot life is strictly observed. Chemically curing adhesives which have exceeded their pot life cannot be applied any longer on the adherend's surface and are disposed.

Note 2 to entry: In some Technical Datasheets instead of the term "pot life" the term "work life" is used.

3.34

qualification of an adhesive

process for proving that the adhesive meets the requirements placed on it

3.35

safety class

performance requirements of the adhesively bonded joint defined on the basis of the potential of damage effect that the failure of the joint can cause

3.36

special process

process where the conformity of the resulting output cannot be validated easily, i.e. usually non-destructively with one hundred percent certainty, or economically

3.37

stress cracking

crack development in plastics as a consequence of the simultaneous action of chemicals (e.g., solvents) and mechanical stressNote1 to entry: The residual stress of a material often suffices for stress cracks to develop.

3.38

surface treatment

treatment of the surfaces of parts to be joined in order to optimise wettability and adhesion and to achieve reproducible adhesively bonded joints with a stability that meets the requirements

3.39

test sample

specially prepared specimen which is the subject of destructive or non-destructive testing

3.40

thermoplastic polymer

class of plastic which can be deformed in any desired way within a specific temperature range, without undergoing a chemical change

NOTE These deformation properties are due to the fact that the polymers are not chemically crosslinked.

3.41

thermoset

type of plastic with polymer chains chemically crosslinked in a narrow-mesh which cannot be deformed in any desired way, without undergoing a chemical change

3.42

user-company

adhesive user

company that uses adhesives and adhesive bonding technology for their production, maintenance and repair

3.43

wettability

ability of a liquid (for example an adhesive) to spread itself on a solid surface so that the adhesive is distributed over as large an area as possible on the adhesive bonding surface and comes so close to the surface that the interaction can take place

NOTE Even though the adhesion is also dependent on other factors, the wetting of the surface is an absolutely necessary condition in order to obtain adhesion between adherend and adhesive, but not the only one.

4 Competences of adhesive bonding personnel

4.1 General

The adhesive user-company shall have at their disposal adhesive bonding personnel with appropriate competences for Adhesive Bonding Operators and Adhesive Bonding Coordinators (rABC/d). Personnel performing adhesive bonding work shall have the necessary competencies, knowledge and experiences for planning, designing, supervising, testing and workmanship in adhesive bonding technology. See also [Annex A](#) for further details.

The work performed by the subcontractor shall also be executed following the requirements of this document.

In case of subcontracting, an external rABC/d of the ordering company shall not work for the subcontracting party.

There are three levels of competencies 1, 2 and 3, see [Table 1](#).

Table 1 — Levels of competencies, knowledge and experiences for adhesive bonding personnel

Level	Scope of competencies, knowledge and experiences
1	Comprehensive technological competences, knowledge and experiences in adhesive bonding technology are fulfilled by the state-of-the-art skills and advanced skills (minimum one-year suitable experience in adhesive bonding technology) Examples in informative Annex B
2	Specific technological competences, knowledge and experiences in adhesive bonding technology are fulfilled by the state-of-the-art skills and advanced skills (minimum one-year suitable experience in adhesive bonding technology) Examples in informative Annex B
3	Basic technological competences, knowledge and experiences in adhesive bonding technology are fulfilled by the state-of-the-art skills. Training and qualification of this level can be approved by rABC/d. In this case the rABC/d has to define the qualification range. Examples in informative Annex B

4.2 Competences of coordinators

Adhesive Bonding Coordinators (rABC/d) have the responsibility for all adhesive bonding activities and shall have sufficient authority to enable any necessary action to be taken.

To this effect, they shall be conferred the necessary managerial authority and entrusted the decision-making powers permitting them to act independent of operational and temporal constraints. Only appropriately qualified personnel shall be appointed as Adhesive Bonding Coordinators (rABC/d). The tasks and responsibilities of such persons shall be clearly defined for subcontractors as well.

The minimum requirements regarding the technological competencies, knowledge, and experiences in adhesive bonding technology for the responsible adhesive bonding coordinator and their deputies are shown in [Table 2](#) for level 1 to level 3, depending on the safety class.

Table 2 — Minimum requirements regarding the technological competencies, knowledge, and experiences in adhesive bonding technology for the responsible adhesive bonding coordinators and deputies

Scope of work	Comments	Class A1 ^a	Class A2 ^a		Class A3 ^a	Class Z ^a
Release of development-phase (pre-production) product and process designing		Level 1	Level 1 for product design <i>with</i> calculation/validation	Level 2 for products <i>without</i> calculation/validation	Level 2	To be defined by the user-company

Scope of work	Comments	Class A1 ^a	Class A2 ^a	Class A3 ^a	Class Z ^a
Supervision of production/manufacturing (in-production and maintenance (post-production) without any process changes outside the defined process definition	In case of new or redesign and/or new processes or process changes go back to first line of this table	Level 2	Level 2	Level 3	To be defined by the user-company
Involvement of rABC in purchase, sales, assembly and sub-contracting of adhesively bonded components	The supply chain shall be a closed loop in a traceable way to ensure that every contract partner has the necessary competencies	Level 2	Level 2	To be defined in the technical specifications	To be defined by the user-company
^a see Table 3 in 5.3.2					

For in-production and post-production the minimum number of personnel with appropriate level of competence required shall be two, e.g. one adhesive operator and one coordinator.

If necessary, one or more rABC/d shall be appointed in a suitable and traceable manner for different scopes. Tasks and responsibilities are to be clearly defined.

ABCs/d who are not permanently employed by the ordering company/manufacturer are treated as external rABC/d. They can be recognized as the ordering company's/manufacturer's rABC/d providing the following conditions are fulfilled:

- the ordering company/manufacturer shall ensure and demonstrate that the external rABC/d is available as necessary to fulfil his tasks;
- the work of the external rABC shall be defined and documented. The date, location, duration, and type of activities shall be recorded.

The adhesive bonding coordination activity is the core issue in the field of application of this document. For this reason, the ordering company/manufacturer shall take particular care in subcontracting adhesive bonding coordination task, especially when:

- rABC/d is subcontracted by a number of companies, or
- the ordering company/manufacturer subcontracts a number of rABC/d.

The level of technological competencies, knowledge, and experiences in adhesive bonding technology is explained in informative [Annex A](#).

4.3 Competences of the adhesive bonding operators

The minimum requirements for the competences of the adhesive bonding operators are explained in informative [Annex A](#).

All adhesive bonding operators shall have the necessary competence, see [Table 1](#), level 3, if class A1 and class A2 adhesive bonds are involved.

5 Design and verification of adhesively bonded joints on rail vehicles

5.1 General

This clause describes the procedure in the case of design, dimensioning, and proof of conformity management for adhesive bonding of metallic and non-metallic materials in the production as well as in the maintenance of rail vehicles and rail vehicle parts. The aim is the design, dimensioning and verification under consideration of all geometrical, material and environmental influences (e.g. cleaning agents, UV radiation, temperature, humidity, etc.).

All parties involved such as user-companies, vehicle suppliers and adhesive manufacturers/suppliers shall take into account the best practices of adhesive bonding including new developments.

5.2 Design process

5.2.1 Flow chart

The flow chart below ([Figure 1](#)) is an example and not a strictly chronological guideline.

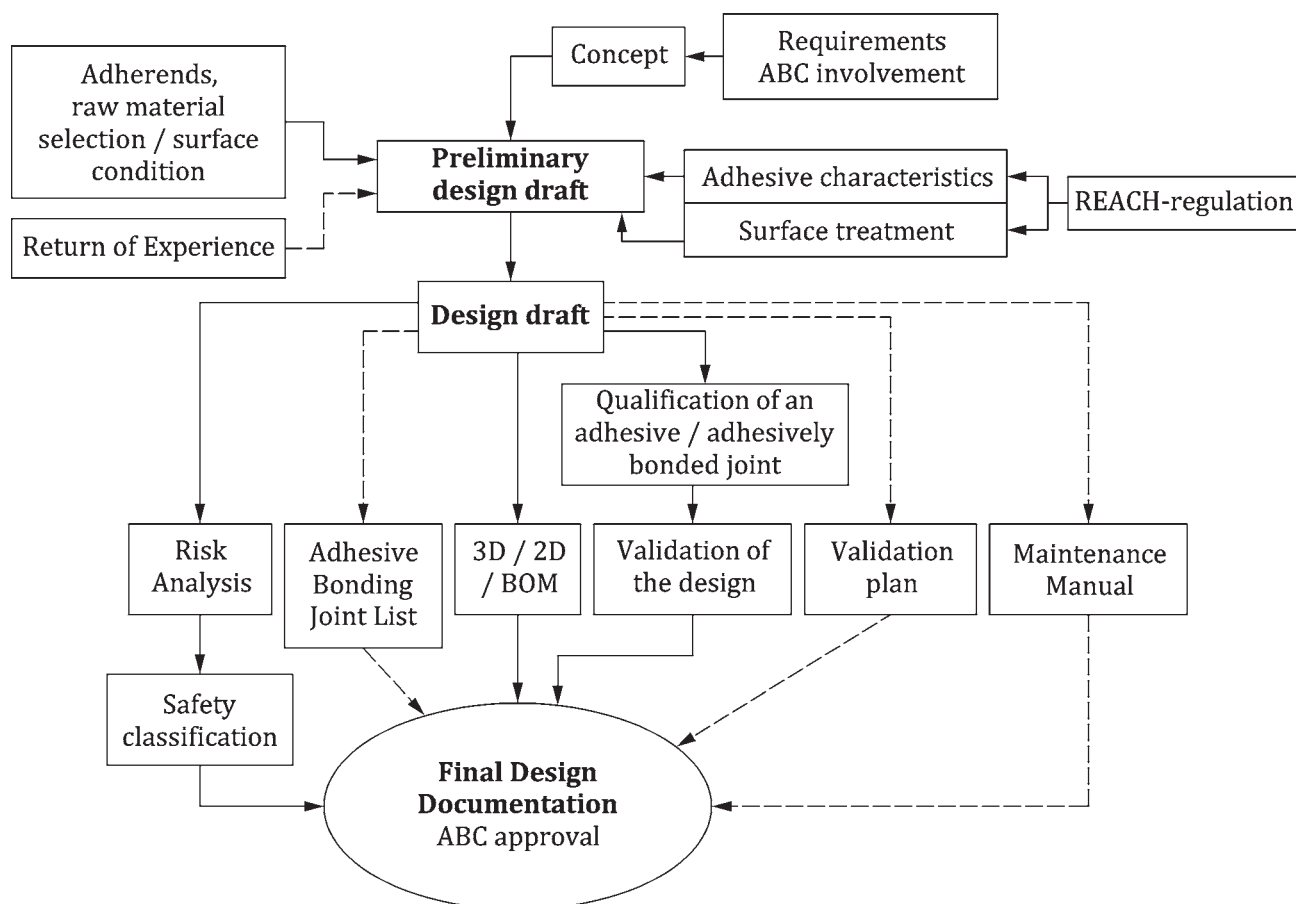


Figure 1 — Flow chart of a design process, dotted line: optional documents to be defined in the technical specifications

5.2.2 List of requirements

Every adhesively bonded joint shall fulfil specific requirements.

At the design stage, a requirement list for the adhesively bonded joints shall be established, which is to be derived from the project specifications (legal, contractual, and internal requirements) and shall be documented.

NOTE 1 All relevant departments of the company should be involved in the description of these requirements.

The loads to which the adhesively bonded joint will be subjected shall be involved in the requirement list.

These loads include static loads (creep and relaxation), vibrations, dynamic loads, chemical and microbial loads, thermal and photochemical loads, and combinations of these if applicable.

NOTE 2 Examples of mechanical loads can be extracted from the general railway standards see [Table C.1](#).

The requirement list shall take into account the life time of the adhesively bonded joint and shall be based on reliable data about type, intensity, duration, and frequency of the loads.

A requirements list shall be established, e.g. using the main parameters as shown in [Table C.1](#). The scope of the requirements list shall be consistent with the classification of the adhesively bonded joint.

5.2.3 Preliminary design and general design parameters

5.2.3.1 Design principles

The design solution will be influenced by the loads or effects from the requirement list. Some general principles are described in [Annex D](#).

5.2.3.2 Selection of the joining part material and the surface condition of the parts to be joined

Adherends and their surface condition shall be selected on the basis of the list of requirements. The raw material and the surface condition shall be taken into account for the surface treatment or the surface properties (e.g. screen print(ing), roughness, etc.). The effects of corrosion or the long-term stability of the parts to be joined shall be determined or based on empirical values. The chemical composition of raw material can influence the adhesive itself or the adhesion.

5.2.3.3 Return on experience

Experiences of previous solutions shall be considered for the design of adhesively bonded joints.

5.2.3.4 Adhesive selection

Adhesives shall be chosen according to the list of requirements (e.g. low modulus adhesive or high modulus adhesive, solidification process, etc./see [Annex E](#)). All available information (data sheets from adhesive suppliers, internal data, return on experience, laboratory advice) shall be used for the selection.

Adhesive selection can be refined throughout the whole design process. In choosing the adhesive bonding system it shall be ensured that the characteristics of the adhesive are not considered in an isolated manner but as part of the adhesively bonded joint in its entirety.

Adhesion to the adhesive bonding surface is a necessary condition for any adhesive bonding and shall be validated by appropriate methods and means. In addition, manufacturing conditions as described in [Clause 5](#) and [Clause 6](#) shall be taken into account (relevant design and manufacturing documentation).

The choice of the adhesive bonding system can be made on the basis of [Annex E](#).

5.3 Design

5.3.1 General

The ability of an adhesively bonded joint to resist external influences is closely related to several factors. These include the physical and mechanical properties of the individual elements and the adhesive bond of the joint, their geometric properties and the extent and scope of application, as well as the type of adhesive and cohesive interactions generated, factors manufacturing technology and occupational safety. All these factors, the cohesion and adhesion that develops during the curing process, shall be determined in the design phase of the adhesively bonded joint.

5.3.2 Risk analysis and safety classification

The classification of each individual adhesively bonded joint is solely and exclusively based on the potential damage that can arise by the failure of the joint itself. Particularly, the consequences of the failure of an adhesively bonded joint shall be evaluated on the basis of safety aspects (risk of fatalities or injury of people) and functional aspects of the system. Every adhesively bonded joint shall be allocated a safety class (see [Table 3](#)):

The safety class defines the consequences of failure of the single adhesively bonded joints in respect to effects on persons, facilities, and the environment.

The classification of adhesively bonded joints or of the sealing shall be carried out by the responsible technical design engineer in cooperation with rABC/d according to the definitions in the following table on the basis of a 'functional risk analysis' (hazard analysis), using failure sequence analysis or RAMS analysis (**R**eliability, **A**vailability, **M**aintainability, **S**afety; see [EN 50126 \[45\]](#)). The safety classification shall be made on the assumption of a complete and spontaneous rupture of the adhesive joint and its effects on persons, the vehicle and the environment. The safety class is derived from the consequences of the failure of an individual adhesively bonded joint in terms of the impact on people, equipment and the environment.

Table 3 — Safety classes of adhesively bonded joints and definition of the safety requirements

Class	Definition of the safety requirements
A1	High safety requirement Failure of the adhesively bonded joint will lead to consequential events with personal injuries or breakdown of the overall function.
A2	Medium safety requirement Failure of the adhesively bonded joint can lead to consequential events with personal injuries or can lead to an impairment of the overall function.
A3	Low safety requirement Failure of the adhesively bonded joint does not lead to any direct impairment of the overall function. Consequential events with personal injuries are unlikely.
Z	No safety requirement Failure of the adhesively bonded joint does not lead to any failure of the overall function and does not lead to personal injuries at normal operational conditions (e.g. leads solely to losses of comfort).

5.3.3 Adhesive bonding joint list

The adhesive bonding joint list is an overview of all adhesively bonded joints of a project or sub-system. If a list of adhesively bonded joints is required, at least the following information shall be provided:

- system designation (project name);
- adhesively bonded joint number or name;

- assembly/sub-assembly number (drawing number, bill of material);
- safety class.

5.3.4 Qualification of an adhesive

5.3.4.1 General

The qualification of an adhesive shall be oriented to the needs of the design of the adhesively bonded joint.

A distinction is made in the following between low modulus (often elastomeric) and high modulus (most often thermoset or thermoplastic) adhesives. When subjected to quasi-static loading (e.g. [ISO 37](#), [EN ISO 527-1](#), [EN ISO 527-2](#) or [EN ISO 527-3](#)), low-modulus adhesives show predominantly nonlinear elastic behaviour and can accommodate high levels of elongation at break. The operating temperature for such adhesives is above the glass transition temperature.

When subjected to quasi-static loading, high-modulus adhesives show predominantly elastoplastic behaviour. In this case, the operating temperature is mostly below the glass transition temperature, although it can exceed this temperature.

In both cases, the main function of the adhesive is to join the adherends. If the adhesive is also designed to accommodate deformations and to compensate for considerable tolerances of the dimensions of the parts to be joined, then nonlinear elastic, low-modulus adhesives are normally used. If the transfer of relatively high loads is involved, high-modulus adhesives are usually used.

NOTE High-modulus adhesives tend to be characterized by higher strength and lower deformability (e.g. $E \gg 100$ MPa, $\epsilon \ll 100$ %), while low-modulus adhesives tend to be characterized by lower strength but higher deformability (e.g. $E \ll 100$ MPa, $\epsilon \gg 100$ %).

5.3.4.2 Physical properties of adhesives

5.3.4.2.1 General

Physical properties shall be determined for each specific adhesive and surface, and for the relevant loading conditions (e.g. moisture, temperature, chemical action, mechanical loading) or combinations of these.

5.3.4.2.2 Adhesive characteristic values

Test samples for determining the stress limit of adhesively bonded joints shall be prepared following the procedures, adherend materials and surfaces to be deployed in service. If cohesive failure of the joint occurs, the failure will be due to the adhesive as such. In such cases, data and characteristic values from tests using other adherents may be used, provided that the test conditions, requirements and strain/deformation behaviour are equivalent, and that the failure in these tests was also cohesive.

5.3.4.2.3 Adhesive bond strength

If not specified otherwise, the cohesive failure ratio for aged or non-aged test samples shall be at least as defined in [Table 4](#).

For adhesion tests, the failure patterns according to [EN ISO 10365](#) below are accepted:

- cohesive failure (CF);
- superficial cohesive failure (SCF);
- substrate failure (SF).

In case of substrate failure, the weakest partner shall be evaluated to ensure the design of the product.

Table 4 — Failure criteria in adhesively bonded joints

Adhesive classification	Failure pattern
Low modulus adhesive with layer thickness $\geq 1,5$ mm	≥ 95 % CF + SCF + SF
High modulus adhesives	≥ 70 % CF + SCF + SF

For cohesive failure ratios lower than the criterion shown in [Table 4](#), additional tests (e.g. regarding ageing behaviour, failure pattern, scatter of results) shall be carried out.

Adhesively bonded joints that have been repaired can have other adhesive bonding characteristics than the original adhesively bonded joints. This shall be considered in the design or analysis of the adhesively bonded joints.

The choice of accelerated ageing tests (see [Annex G](#)) will depend on the requirements profile.

The results of low modulus and high modulus adhesives (see below) are valid only for the characterization of the adhesives. The interpretation of the results of the work samples produced in the production shall be defined according to [Table 4](#) under the responsibility of the rABC.

Depending on the relevant requirements, low-modulus elastomeric adhesives can be subjected to the bead peel test as in [ISO 21194](#) (following exposure to chemical agents, where appropriate). It shall be noted, however, that this test only provides a result on adhesion. Its results are suitable for selecting adhesives and surfaces or for quickly checking adhesion or for making comparisons. It does not provide strength values which can be used in the design of the adhesively bonded joint. Such adhesive bonding values are to be obtained by other tests (see [E.3](#)).

For high-modulus adhesives, proof of adequate adhesion shall be taken into account during mechanical tests (e.g. lap shear, tensile test, pull-off test, etc., see [Annex F](#)). The failure pattern shall be analysed and defined according to the [EN ISO 10365](#).

5.3.4.3 Load capacity

Load capacity values are obtained by testing adhesively bonded joints. In the analysis, characteristic values shall be determined as in [Annex D](#) for class A1 adhesively bonded joints with a confidence interval of $1 - \alpha = 95$ % according to [ISO 16269-6](#). The probability shall be at least 95 %. For class A2 adhesively bonded joints, characteristic values shall be determined with a confidence interval of $1 - \alpha = 95$ % and the probability rate shall be at least 90 %.

The load capacity is expressed as the characteristic value for the possible stress limit (see [Annex D](#)) under the relevant operating conditions.

Load capacity can be described using suitable equivalent stress/strain considerations. For the sake of consistency, when analysing local stress and stress resistance, the same considerations shall be made.

The load capacity can also be derived from available equivalent results or experience gained in practice.

5.3.4.4 Quasi-static adhesive bond strength

Adhesives shall be tested in accordance with [Annex D](#). Special assemblies such as adhesively bonded sandwich panels, adhesively bonded honeycomb sandwich panels and foamed materials shall be tested in accordance with the relevant technical rules. In all cases, the characteristic value (see [Annex D](#)) shall be given and the failure pattern shall be described (see [EN ISO 10365](#)). If the operating conditions and the safety class so require, the adhesive bond strength shall be determined as a function of the temperature or following exposure to chemical agents.

5.3.4.5 Creep behaviour, creep limits, relaxation and elongation at break under long-term static loading

When determining the creep behaviour of the adhesively bonded joint, two different operating conditions shall be assumed:

- a) Creep: The adhesively bonded joint is to be subjected to a permanent static load (e.g. self-weight of the component), i.e. the elongation increases continuously as long as the creep limit of the adhesively bonded joint is low. The admissible creep strain at a given point in time (to be specified by the technical designer) is to be used in the design of the adhesively bonded joint to ensure that the stress resulting from the static load is smaller than the stress that leads to the permissible creep strain. The permissible creep strain shall be smaller than the elongation at break after relaxation or creep (see item b) below). Information on creep behaviour measurements is given in [Annex D](#).
- b) Relaxation: The adhesively bonded joint shall be designed to accommodate the relative displacement of the components for a prolonged period (e.g. any fittings after the adhesively bonded joint was manufactured, deformation due to dimensional deviations, deformation due to pre-stresses during assembly, any deformation resulting from varying temperatures for large components such as roof panels of glass fibre-reinforced plastics (GRPs)). Failure of the adhesively bonded joint in the relaxation test is unlikely. The permissible elongation is to be determined by testing. Information on how to test elongation at break after relaxation is given in [Annex D](#).

Case b) is normally relevant only if low-modulus, elastomeric adhesives are used. The elongation at break after relaxation is markedly lower than that measured when determining the tensile lap-shear strength (see [Annex F](#)) or creep and static loading (case a) in a quasi-static test.

The elongation at break after relaxation or creep is a function of the temperature, the effect of chemical agents, and the surface of adherends.

5.3.4.6 Vibrational stress and fatigue

The allowable vibrational stress of the adhesively bonded joint is a function of the adherend materials, any surface coatings, the adhesive, and the operating conditions, given due to consideration of the influence of the mean stress (susceptibility to creep). Information on the measurement of fatigue strength is given in [Annex D](#).

5.3.4.7 Crash/impact behaviour

The mechanical properties of adhesives and adherends are a function of temperature and strain rate. To characterize the adhesively bonded joint behaviour at high rates of loading, the adherend and adhesive bonding characteristics shall be determined at the relevant strain rates.

The properties of the adhesively bonded joints shall be tested in cases for which the adhesively bonded zone markedly affects the behaviour of the structure on exposure to impact or collision.

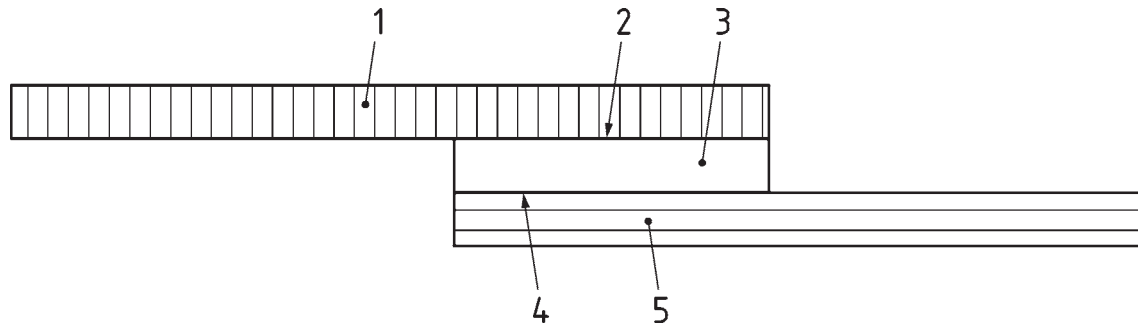
5.3.4.8 Design and manufacturing documentation

For every assembly, design documentation shall be done (3D-models, 2D drawings, bill of material, etc.). These documents shall contain all information needed for creating the manufacturing documents and executing the manufacturing process. Therefore, the minimum content of these documents for adhesive joints shall be:

- adherend material;
- adherend surfaces;
- adhesive;
- surface treatment;

- dimensions and positions, if necessary including tolerances;
- safety class, and
- reference to this document.

[Figure 2](#) gives an example how this information can be implemented into drawings. It is essential that a precise link between surface pre-treatment and adherend surface is implemented into the design documents.



Key

- 1 adherend 1 including surface definition
- 2 surface treatment 1
- 3 adhesive
- 4 surface treatment 2
- 5 adherend 2 including surface definition

NOTE Adhesive bonding symbols simplify the drawings.

Figure 2 — Example 2D-drawing for adhesively bonded joints

5.4 Validation of the design

5.4.1 General

The scope of the validation depends on the class assigned to the adhesive bond (see [Table 2](#)). The validation of the design can be made using one of the methods below:

- 1) calculation of the adhesively bonded joint (e.g. stresses and strains) for each adhesively bonded joint and comparison with the load capacity (see [5.4.3](#));
- 2) tests of components or parts of these under realistic conditions so as to determine the strength of parts of the assembly (see [5.4.5](#));
- 3) proven design by documented experience (see [5.4.4](#)).

Methods 1, 2, and 3 can be combined.

5.4.2 Identifying of the influences/loads

5.4.2.1 General

Load cases are determined by the requirements. The adhesively bonded joints are calculated from these load cases.

5.4.2.2 Examples of mechanical loads

Some examples of mechanical loads are listed in [Table 5](#).

Table 5 — Examples of mechanical loads

	Static		Dynamic/Cycling
	Short term	Long term	
Example	Quasi-static (directional load cases), shock/impact, crash	Creeping, relaxation (permanent displacement)	Fatigue vibration aerodynamic loads

5.4.2.3 Examples of non-mechanical loads

Some examples of non-mechanical influences are listed in [Table 6](#).

Table 6 — Non-mechanical influences to adhesively bonded joints

	Chemical and micro-bio-logical influences	Thermal and other physical influences
Example	Moisture (corrosion), cleaning agents de-icing	Thermal, photochemical (UV), electromagnetic, electric

For all influences mentioned in [Table 5](#) and [Table 6](#), the following parameters shall be taken into account:

- type (direction);
- intensity;
- duration;
- frequency.

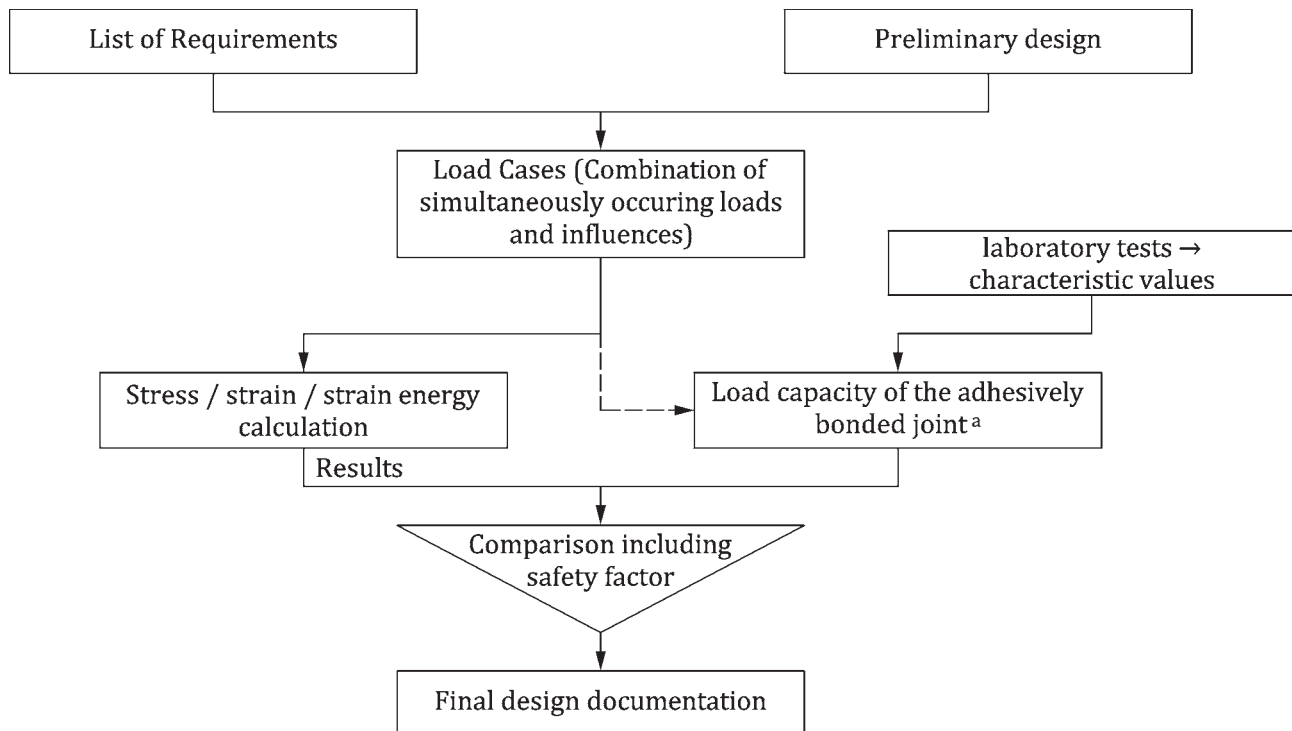
A load case is a combination of previous influences and parameters which will impact the adhesively bonded joint at the same time. In general, for one design it is typical to have various load cases.

The relevant load cases shall be integrated in the validation plan of the adhesively bonded joint.

5.4.3 Calculation

5.4.3.1 General

The result of the verification (see [Figure 3](#) below) is a comparison between the calculated loads that occur in the adhesively bonded joint and the load capacity of the adhesively bonded joint.



NOTE Safety factors depend on the knowledge or experience of the company. Safety factors are defined by user-companies based on their knowledge or experience.

^a Characteristic values for the applicable loads/influences

Figure 3 — Calculation process

5.4.3.2 Determining stresses/strains

5.4.3.2.1 General

Structural design is to be performed using an analytical approach or finite element analysis (FEM analysis). The design methods used and the results obtained shall be validated in a transparent way using comparative calculations for suitable tests on simple test pieces, mock-ups or available results of component testing. Test pieces or mock-ups showing a distribution of forces and having a geometry similar to that of the adhesively bonded joint considered are deemed suitable. Available knowledge and experience gained may also be drawn on.

Loads shall be derived from the requirement profile (see [Clause 5](#)). Adhesively bonded joints shall be analysed as a function of the elasticity of the adhesive and the respective load case, taking into account stress (strength) or strain (deformation).

The adherend surface, stress concentrations in the adhesive bond and the properties of adherends and their surfaces are decisive for the loadbearing capacity of the adhesive bond. Normally, only a few load cases from among a number of theoretical cases, or a combination of these, are significant for dimensioning purposes.

5.4.3.2.2 Finite element method (FEM)

The finite element method (FEM) permits the determination of local stresses in adhesively bonded joints. In the calculation, either spring elements or other equivalent elements can be used, or the stresses in the joint can be calculated with a high level of accuracy by assuming volume elements and the corresponding material models.

If spring elements are used – which is often the case in the analysis of nonlinear elastic thick-film adhesive bonds – the spring constant resulting from the lateral strain confinement depends on the adhesive bond line thickness and adhesive bond width and the direction of loading, where the adhesive bond is subjected to tension or compression. If other equivalent elements are used, the effects of any simplification shall be considered.

For a more rigorous analysis of local stresses, an adequately refined mesh is necessary. The accuracy of the material models and the finite element meshes used shall be validated in a transparent way by means of suitable checking or comparative calculations (e.g. single element analyses, calculating the behaviour of samples or simple mock-ups), or by means of suitable experimental or convergence analyses.

5.4.3.2.3 Analytic calculation methods

In general, the analytic calculation methods are similar to the finite element analysis. The process steps: modelling/simplified sketch, description of material behaviour of the different adherends of the adhesively bonded joint and the comparison between calculated load and permissible load stress shall be performed in both cases.

The adhesively bonded joint shall be described with standard mechanical/structural elements, like trusses, beams, plates, shells, etc.

The nominal approach is a simple analytical concept. The adherend shall be modelled as a rigid body and the adhesive as a linear elastic body. The forces are uniformly distributed. The quotient of force and adhesive area shows the normal tension. The normal tension shall be compared to the permissible tension. The nominal approach is often used for pre-dimensioning.

To calculate the design in a more precise way there are the following possibilities, an unbalanced strain and stress behaviour is the result:

- description of the adherend material behaviour, i.e. the deformations seen by the complete product;
- onset of forces and torques in an unbalanced manner and multiaxial stress level;
- respect of influences (temperature, humidity, tension force) of the material behaviour.

5.4.3.3 Load capacity of the adhesive

Characteristic values from the qualification of the adhesive shall be used. In case the qualification of the adhesive was not done on the same conditions (e.g. adherends, temperature, humidity, etc.) as required, a combination of characteristic values (from the qualification of the adhesive) shall be considered.

5.4.3.4 Validation of load capacity of the adhesively bonded joint

In order to determine the influence of production on the permissible values, test samples for adhesively bonded joints class A1 and A2 shall be produced and tested once for a selected application under production-relevant conditions. Type, extent and evaluation criteria are defined by the rABC.

5.4.3.5 Comparison including safety factor

The calculated stress and strain shall be compared to the permissible values.

A safety factor shall be integrated and documented in the calculation according to the knowledge or experience of the company.

- Case 1: Calculated stress and strain exceed the permissible values, the design shall be improved or reconsidered;
- Case 2: Calculated stress and strain are below the permissible values; the design of the adhesively bonded joint is verified.

5.4.4 Proven design

If verification is based on experience, proof shall be provided that the system has proven itself to be adequate. To this effect it shall be demonstrated that the behaviour of the adhesive bond under service conditions can be applied to the adhesive bond under consideration in terms of service life, loading conditions and adhesive bond properties. The procedure shall be documented in a transparent way.

5.4.5 Component test

Component test is understood to be testing the system as a whole or part of it under actual conditions or conditions reproducing the service conditions. Test conditions shall be adequately similar in terms of their effect on the adhesive bond, proof of which is to be provided. When testing partial systems, the interaction between these and the system as a whole shall be considered and verified so as to make sure that the interaction does not unduly affect the results. For evaluation purposes, a failure criterion shall be specified. Test results shall be adequately evaluated statistically. Depending on the knowledge regarding the adhesive bond, how far the test conditions are realistic, and the statistical evaluation applied, a safety factor shall be integrated into the failure criterion or test conditions. The overall process shall be documented. Any decisions made and justifications for them shall be documented.

5.4.6 Combination of calculation/component test/proven design

If the verification is affected by combining the above methods, it is to be ensured that all requirements are adequately considered. Care shall also be taken to ensure that all parts of the verification process are mutually compatible (e.g. if comparing test results with pass/fail criteria). The procedure shall be documented in a transparent way.

5.5 Proof of conformity

Upon successful proof of conformity of the design, the rABC shall endorse the release in accordance to [Table 7](#) of this document. In addition, the result of the conformity of the design shall be recorded in the engineering documents.

[Table 7](#) provides an overview of the measures to be performed/implemented for adhesively bonded joints of classes A1 to A3. For class Z adhesive bonds, only the classification shall be documented.

The level of detail of the measures to be taken depends on the requirements relevant in the particular application and justified in accordance with the rABC/d.

**Table 7 — Measures and documentation in the proof of conformity
for the safety classes A1, A2, A3 and Z**

		Safety class			
		A1	A2	A3	Z
Design of adhesive bond					
1	Classify adhesive bond, draw-up requirements list	A	A	A	A
2	Choose adhesive bonding system	A	A	A	A
3	Design assemblies, components and adhesively bonded joints	A	A	A	A
Documentation					
4	Classification of adhesively bonded joint, with justification	D	D	D	D
5	Requirements list	D	D	—	—
6	Test reports including material characteristics, adhesive bonding parameters, return of experience	D	—	—	—
7	Technical data sheets	D	D	D	—
Calculation for dimensioning (e.g. FEM analysis, analytical approach)					

		Safety class			
		A1	A2	A3	Z
8	Design is based on the state of the art and/or the results of the component tests and/or the documented experience that no damage has occurred so far.	D	—	—	—
	Approximate calculation, comparison with experience gained	D	D	—	—
9	Determination that load is less than load capacity (for dimensioning load cases, if necessary, taking safety factors into account)	D	D	—	—
10	Design documents, checked with respect to adhesive bonding work	D	D	D	—
Determination of the load					
	Exact analysis of all load cases described in the requirement profile, identification of their relevant combinations, determination of the dimensioning load cases				
11	Identification of all relevant combinations, establishing load cases to be considered	D	—	—	—
12	Rough estimate for load cases to be considered	—	D	—	—
Load capacity including adhesion					
13	Testing relevant material combinations on exposure to heat/cold and moisture, with assessment of failure pattern	DP	DP	—	—
	Manufacturer's data	D	D	D	—
14	Strength of adhesively bonded joint without ageing, testing in standard atmosphere)	DP	DP	—	—
Determination of characteristic values (according to the dimensioning load cases determined in Item 11 or Item 12)					
15	Adhesive properties and adhesive bond strength under the required mechanical physical, medial and load	DP	DP	—	—
	Creep behaviour, creep limits under static loading	DP	DP	—	—
	Elongation at break after relaxation under static loading	DP	DP	—	—
	Vibrational stress	DP	DP	—	—
	Crash/impact behaviour ^a	DP	DP	—	—
	NOTE: Other characteristic values shall be determined if relevant for the calculation of the design load cases.				
16	Validation of exemplary values under production condition and considering the statistic influence to compare with characteristic values	DP	—	—	—
Key A: Action to be carried out D: Documentation DP: Documentation, including test report/record -: Optional action					
^a The properties of the adhesively bonded joints are to be tested at the relevant strain rates in cases where the adhesively bonded zone markedly affects the behaviour of the structure on exposure to impact or collision (see e.g. EN 15227 [42] , EN 12663 [5] , EN 13749 [44]).					

6 Workmanship

6.1 General

All adhesive bonds (classes A1 to Z, see [Table 3](#)) shall be manufactured in accordance with the following requirements if they are relevant for the process and the particular class.

The process shall be planned and performed so as to ensure a safe and reproducible working procedure. Some major criteria for performing the adhesive bonding process are given in this clause.