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Adhesives — Guidelines for the fabrication of adhesively bonded structures and reporting procedures suitable for the risk evaluation of such structures

Adhésifs — Lignes directrices pour la fabrication des structures collées par adhésifs et procédures pour l'établissement de rapports pour l'évaluation des risques liés à ces structures

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 11, *Products*.

This second edition cancels and replaces the first edition (ISO 21368:2005), which has been technically revised.

The main changes compared to the previous edition are as follows:

— broadening of the terms and definitions to include relevant processing and manufacturing terms;

— classification of adhesively bonded joints according to safety requirements;

— clarification of the competences, knowledge and experience of adhesive bonding personnel;

— comprehensive explanation the design of adhesively bonded joints;

— thorough description of surface treatment procedures;

— extensive account of how to assemble/manufacture of adhesively bonded joints.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Adhesive bonding technology is used widely internationally to fabricate many of the structures in the adhesive-using industry. In some companies, it is the key feature to production. Such structures range from microelectronic encapsulation to the structure and reinforcement of aircraft wings and bridges. Adhesive bonding technology appeals to industry across sectors and applications because it allows flexibility in the selection of materials, product design and product manufacture up to the final assembly. As such, adhesive bonding technology exerts a profound influence on the cost of fabrication and the quality of the product, thus allowing significant production savings and a competitive advantage in comparison with traditional methods of manufacture. It is important, therefore, to ensure that adhesive bonding technology is carried out in the most effective way and that appropriate control is exercised over all aspects of the operation. If used properly and professionally, the adhesive bonding technology is undoubtedly able to meet the requirements of circular economy and eco-design.

Within the ISO 9000 series of standards for quality systems, adhesive bonding technology is to be treated as a "special process" since adhesively bonded joints cannot be fully verified by subsequent inspection and testing of the product to ensure the required quality standards have been met.

As per today's knowledge, adhesively bonded joints cannot be inspected into a product. The task is to install them faultlessly from the outset. Even the most extensive and sophisticated non-destructive testing does not improve the quality of adhesively bonded joints.

For adhesively bonded structures to be effective and fit for purpose in service, there is a need to provide controls from the design stage through material selection to manufacture and subsequent inspection. Poor design for adhesive bonding creates serious risks and costly difficulties in the workshop, on site or in service. Inadequate consideration of the materials to be adhesively bonded and the choice of adhesive may result in adhesive bonding problems such as lack of adhesion or inadequate gap-filling of the structure. It is therefore essential for adhesive bonding procedures to be correctly formulated and approved to avoid imperfections. Comprehensive and qualified supervision ensures that the specified quality is achieved.

To ensure the quality of adhesively bonded structures on an international level and to make the quality of adhesively bonded structures internationally comparable, the task of management is to:

— identify possible sources of error;

— create organizational structures that prevent these sources of error from the outset; and

— introduce suitable quality procedures.

For these reasons, this document represents the state of the art for the professional organization of adhesive bonding processes in all areas of industry and trade in a holistic and international view. It also applies analogously to sealing processes if the function of the seal is only to secure and support adhesively bonded joints. The consideration of adhesive bonding technology according to this document comprises, starting with the first idea, the development of adhesively bonded joints (pre-production), continues through production, i.e. the manufacture of adhesively bonded joints (in-production), to the finished adhesively bonded product including its maintenance, repair and disposal (post-production).

This holistic approach also includes the quality assurance of production, inspection and maintenance, including the repair and disposal of adhesively bonded joints. The approach according to this document is, without exception and in any case, independent of the lot size as well as the respective area of application.

This document establishes definitions and sets out organizational, management technical, contractual and technical principles to be followed when manufacturing adhesively bonded joints. This is achieved by defining three essential core elements:

— Core element 1: the classification of each adhesive bond according to safety requirements (see Clause 4);

— Core element 2: the appointment of supervisory personnel [Adhesive Bonding Coordinators (ABCs)] and execution personnel (Adhesive Bonding Operators) who are both capable of objectively verifying the necessary and required adhesive bonding competence, knowledge and experience in each case (see Clause 5);

— Core element 3: the verification that the real load of the respective adhesive bond in the use and application of the adhesively bonded product is in any case less than the maximum load bearing capacity (see Clause 6).

The above-mentioned, necessary worldwide comparability in quality and implementation is achieved through a uniform implementation of these three core elements at the international level.

Since the all numerical values described in this document are reference values, it is advisable for the practitioners to decide on their own when implementing them.

Adhesives — Guidelines for the fabrication of adhesively bonded structures and reporting procedures suitable for the risk evaluation of such structures

1 Scope

This document provides guidelines describing the adhesive bonding quality requirements suitable for use by adhesive user-companies utilizing adhesive bonding as a means of fabrication. In particular, the guidelines define various approaches to meeting quality requirements for fabrication and reporting procedures, both in workshops and on site. These guidelines aim to convey the importance of maintaining quality standards in fabrication and reporting procedures, keeping records and thus enabling documentation to provide the basis for risk evaluation of adhesively bonded structures in service and in use.

These guidelines have been prepared such that:

a) they are independent of the type of adhesively bonded structure;

b) they are independent of adhesive user-companies' and suppliers' product recommendations;

c) they define the quality requirements for adhesive bonding in terms of fabrication and reporting procedures, both in workshops and on site;

d) they can be used as the basis for risk evaluation of adhesively bonded structures in service and in use;

e) they can be used as a basis for assessing a fabricator's capability to produce adhesively bonded structures fulfilling specified quality requirements when they are detailed in one or more of the following:

   — a contract between the parties involved;

   — an application standard;

   — a regulatory statement.

The guidelines contained within this document can be adopted in full or selectively chosen by the adhesive user to suit the structure concerned. The guidelines provide a flexible framework for the control of adhesive bonding activities in the following cases.

Case 1

The provision of specific requirements for adhesive bonding in contracts that require the adhesive user to have a quality system other than ISO 9001.

Case 2

The provision of specific requirements for adhesive bonding as guidance to an adhesive user developing a quality system.

Case 3

The provision of specific requirements for references in application standards that uses adhesive bonding as part of its requirements or in a contract between relevant parties.

Case 4

The provision of a framework for fabrication and reporting procedures to a quality standard, suitable in particular as a basis for the risk evaluation of adhesively bonded structures.

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.

ISO 472, *Plastics — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 472 and the following apply.

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

Note 1 to entry: In adhesive bonding processes, the term adherend is often used as a synonym for substrate.

3.2
adhesion
interaction between the adhesive and the *adherend/substrate* (3.1) surface

Note 1 to entry: The interactions that make up adhesion are based on forces between the surface of the adherend/substrate and the adhesive film and include physical interactions, chemical bonds and micromechanical interlocking.

Note 2 to entry: Adhesion occurs in nm-dimensions.

3.3
adhesion promotor
primer
liquid used in surface treatment to improve the adhesion of the adhesive to the *substrate/adherend* (3.1)

Note 1 to entry: Adhesion promotors often are named as primers, accelerators or activators.

3.4
adhesive
non-metallic material, which joins two *adherends/substrates* (3.1) together via adhesion and cohesion

3.5
adhesive bonding
special process for joining of *adherends/substrates* (3.1) by using an adhesive

Note 1 to entry: The adherends/substrates can be made of the same as well as of different materials and can have different surface characteristics.

3.6
adhesive bonding area
area used to join two *adherends/substrates* (3.1) using an adhesive

Note 1 to entry: Usually the product of the overlap length and overlap width of the adherends/substrates.

3.7
adhesive bonding coordinator
ABC
responsible adhesive bonding coordinator
rABC
competent person with proven professional skills in adhesive bonding technology responsible for the supervision and release of the adhesive bonding processes and for all activities associated with it including the release

Note 1 to entry: The responsible adhesive coordinator (rABC) is the appointed head of all adhesive bonding processes including their release and with the appropriate decision-making managerial authority concerning the adhesive technology within the company.

3.8
adhesive bonding operator
ABO
execution personnel with proven corresponding knowledge applying or executing independently the adhesive bonding process to manufacture, maintain or repair components according to approved work instructions

3.9
adhesive bonding personnel
ABP
people involved in the design, planning, manufacturing, quality assurance and maintenance/repair related to the adhesive bonding process

Note 1 to entry: As a rule, this employee group consists of *ABCs* (3.7) and *ABOs* (3.8).

3.10
adhesive bonding procedure
all processes concerned with adhesive bonding such as surface treatment, processing the adhesive, application of the adhesive, joining the *adherends/substrates* (3.1), and solidification (curing/hardening)

3.11
adhesive bonding surface
area prepared for adhesive bonding, or on which the adhesive is applied, or the surface of the part to be adhesively bonded with adhesive between two parts to be adhesively bonded [length of overlap × width of overlap mm)]

3.12
adhesively bonded joint
connection of two or more substrates (adherends) from the same material or different materials with the use of an adhesive

Note 1 to entry: 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.

3.13
adhesively bonded structure
structure
structure used for a partially or fully finished constituent or any other form of adhesively bonded item and designed mainly to transmit mechanical loads

Note 1 to entry: The loadbearing function is the main role of the adhesively bonded item ensuring reliability and fitness-for-purpose throughout the life cycle of the finished product.

3.14
adhesive tape
flexible backing or carrier coated with a pressure-sensitive, moisture- or heat-activated adhesive

3.15
ageing
entirety of all irreversible chemical and physical processes occurring in a material in the course of time

Note 1 to entry: This can relate to:

— evolution of the properties of adhesively bonded joints with time;

— reproduction of the real operating life through accelerating (reduce time) test of ageing in appropriated environment (chemical and mechanical).

3.16
application
placement of the adhesive during the adhesive bonding procedure

3.17
assembly
group of parts that has been placed together for adhesive bonding or has been adhesively bonded

3.18
clamping
holding of an adhesively bonded joint under pressure with clamps during solidification of the adhesive between the adherends

3.19
cohesion
internal strength that, for example, keep the molecules of an adhesive together

Note 1 to entry: These forces 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.

3.20
component
one part of an adhesive system

Note 1 to entry: In adhesive bonding technology, the parts of an adhesive system (resin and hardener) are called components (component A and component B).

3.21
conditioning
exposure of *components* (3.20) and joining parts required for the adhesive bonding process for a reasonable period in compliance with the specified requirements

3.22
curing
chemical solidification of the adhesive

Note 1 to entry: Chemical reactions leading to solidification of the adhesive in the form of thermoplastic, elastomeric or thermoset polymers.

Note 2 to entry: This refers to chemically curing adhesives.

3.23
curing time
period of time required to solidify an adhesive *curing* (3.22) by chemical reactions

3.24
destructive testing
analyses, tests and surveys carried out for the definition of information of qualitative/quantitative about specific properties of the analysed system, obtained following the destruction of the system itself

Note 1 to entry: The test specimen will be destroyed during the test and cannot be used afterwards.

3.25
exposure time
length of time for which adhesively bonded joints are exposed under specified conditions

3.26
fabricator
adhesive bonding workshops and/or sites under the same technical and quality management

Note 1 to entry: See *user-company* (3.59).

3.27
flash off-time
minimum waiting time when using cleaners, activators or primers until the solvent has completely evaporated

3.28
high-modulus adhesive
load-bearing adhesive
structural adhesive
adhesive where strength and stiffness are the most important properties after solidification

Note 1 to entry: In contrast, there are low-modulus adhesives.

Note 2 to entry: After solidification, high-modulus adhesives concentrate on their strength and stiffness, and less on their formability.

Note 3 to entry: The property transitions between high and low-modulus adhesives are fluid and not precisely defined [see *low-modulus adhesive* (3.37)].

Note 4 to entry: The term "structural adhesives" is often used for high-modulus adhesives. For the purposes of this document, the term "structural adhesives" is replaced by "load-bearing adhesives" (analogous: “load-bearing adhesive bonds” instead of “structural bonds”).

3.29
hot spot
small region or area with a high value of a quantity

EXAMPLE Stress, strain, energy.

Note 1 to entry: A hot spot can be calculated with FEM.

3.30
joining
assembling of *components* (3.20) to become a whole

EXAMPLE Adhesive bonding is just one joining method. Other examples are welding, screwing and riveting.

3.31
influence
non-mechanical parameters that are applied to a material which changes its properties

Note 1 to entry: The nature of the non-mechanical parameters influences the material behaviour (loading) and the load capacity to be selected.

Note 2 to entry: Further influences can have an impact on the adhesive selection.

3.32
in-production
all adhesive bonding activities after preparation, which are connected with the execution of the respective adhesively bonded joint/component until its completion

Note 1 to entry: See *pre-production* (3.42).

3.33
load
mechanical parameters that are applied to a material and lead to stresses and strains (deformations) in the material

Note 1 to entry: The type of mechanical parameters influence the material behaviour (stress, strain and/or strain energy) and the *load capacity* (3.34) to be selected.

3.34
load capacity
limit of the adhesively bonded joint to withstand stress, strain and strain energy

Note 1 to entry: The load capacity can be a permissible value.

3.35
load case
combination of loads and influences applied to an adhesively bonded joint at the same time

Note 1 to entry: 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 in the adhesively bonded joint and are basis for the determination of handling strength and commissioning times.

3.36
loading
physical results in the adhesively bonded joint due to the load and influence combinations defined in the *load case* (3.35)

Note 1 to entry: Physical results of the calculation can be e.g. stress, strain and/or strain energy.

3.37
low-modulus adhesive
adhesives that show an elongation at break of at least 100 % and a modulus of elasticity of at most 10 MPa after solidification

Note 1 to entry: This definition is adapted from ISO 21194. There is no scientifically exact definition. In these adhesives, the deformation properties are the dominant and less their strength and stiffness. Their opposites are the high-modulus adhesives. These adhesives concentrate on their strength and stiffness after solidification. The deformation properties take a back seat. The property transitions between high and low modulus adhesives are fluid.

3.38
mechanical properties
features relating to the behaviour of an adhesive or adhesively bonded joint when subjected to external physical forces (tensile forces, shear forces, abrasive forces, compressive forces, torsional forces, lap shear forces, etc.)

3.39
non-destructive testing
analyses, tests and measurements performed using methods that do not change the material and do not require the destruction or removal of samples of the test system, aimed at the investigation and identification of defects of the structure itself

Note 1 to entry: Each test specimen can be used afterwards without compromising the functioning of the product.

3.40
post-production
all adhesive bonding activities after the execution of the adhesive bonding

Note 1 to entry: These activities include, among other things, the testing and evaluation of work samples during production, the adaptation of the adhesive bonding process, if necessary, the non-destructive testing (e.g. visual) of the manufactured adhesive bonds, the execution of repairs and repair work as well as disposal.

Note 2 to entry: See *in-production* (3.32).

3.41
pot life
period of time during which a reactive adhesive shall be applied after mixing (the maximum processing time)

Note 1 to entry: This time depends on the speed of the chemical reactions responsible for polymer formation (curing speed) and also on the external boundary conditions (temperature, amount of mixture prepared). In order to create high-quality adhesive bonds, the pot life is strictly adhered to. Chemically curing adhesives that have exceeded their pot life are to be treated as waste and are unsuitable for application to joining surfaces. The pot life varies with the volume and temperature of the mixed adhesive and the environment.

3.42
pre-production
all adhesive bonding activities prior to execution of the adhesive bonding

Note 1 to entry: These activities include the development and planning (including work preparation and workplace preparation) of the respective adhesive bonding and the respective adhesive bonding processes. In addition, verification that the real load of the adhesively bonded joint is always smaller than the maximum load capacity in the application (see Clause 6). After that, the adhesive bonding process can also be implemented in the respective production in the planned manner.

Note 2 to entry: See *in-production* (3.32).

3.43
pressure-sensitive adhesive
adhesive that, in a dry state, is permanently tacky at room temperature and adheres readily to surfaces under light and brief pressure

Note 1 to entry: Pressure-sensitive adhesives are used, for instance, for the manufacture of pressure-sensitive tape.

3.44
qualification of the adhesive
process for proving that the adhesive meets the requirements placed on it

3.45
competent personnel
employees who have the required competences, knowledge and experience in adhesive bonding technology, who have acquired this through further training with a recognised credential, vocational training or comparable adhesive bonding technology activities and who can objectively verify this through recognised documents and unequivocally prove it

3.46
quality plan
plan to define and document how customer requirements are to be met

3.47
reproducibility
correspondence between the individual results obtained by the same procedure on identical tests

Note 1 to entry: This applies here to bonds produced under different conditions (different operators, different instruments, different laboratories, different laboratories) and/or at different times.

3.48
safety class
performance requirements of the adhesively bonded joint defined based on the potential of damage effect that the failure of the joint can cause

3.49
safety data sheet
(SDS)
product-specific data sheet containing important safety information about that product

3.50
special process
manufacturing process or process step that cannot be tested by non-destructive means with one hundred percent certainty for any faults

Note 1 to entry: The basic idea is to eliminate all possible errors already during the entire manufacturing process by monitoring the complete production process. This is achieved by the introduction and implementation of an adapted quality management system (e.g. ISO 9001), which is specifically designed for adhesive bonding with the help of this document.

Note 2 to entry: Continuous monitoring and/or compliance with documented procedures are basic requirements to ensure that the specified requirements are met.

3.51
stress cracking
crack development in plastics because of the simultaneous action of chemicals (e.g. solvents) and mechanical stress

Note 1 to entry: The intrinsic stress of a material often suffices for stress cracks to develop.

3.52
stress distribution
spreading of forces across an adhesively bonded surface

3.53
surface treatment
treatment of adherend surfaces in order to optimize the wettability, the adhesion, and give reproducible adhesively bonded joints having good long-term stability

3.54
tack
property of a material that enables it to form a bond immediately on contact with another surface, which can be an adherend or another layer of adhesive

Note 1 to entry: Stickiness describes the ability of the adhesive surface to deform and flow, wetting the second surface immediately on contact, thereby forming a bond. The stickiness test with the finger is a subjective assessment of stickiness.

3.55
technical data sheet
TDS
information sheet prepared by an adhesive manufacturer about the product

Note 1 to entry: It gives information about the properties of an adhesive, and how to process and apply the adhesive.

3.56
tensile test
determination of the strength of a solid, such as an adhesive or an adhesively bonded component

Note 1 to entry: A test bar is subjected to an increasing load in a testing machine.

3.57
thermoplastic
class of plastics whose polymers are not chemically cross-linked with each other and which can therefore be deformed at will within a certain temperature range without undergoing a chemical change

3.58
thermoset
type of plastic with polymer chains chemically crosslinked in a narrow-mesh that cannot be deformed in any desired way, without undergoing chemical change

3.59
user-company
adhesive user
adhesive using-company
company using adhesives and adhesive bonding technology for their production, maintenance and repair

Note 1 to entry: See *fabricator* (3.26).

3.60
wetting
ability of a liquid (for example an adhesive) to distribute itself on a solid surface and to cling to a solid surface

Note 1 to entry: Even though the adhesion is also dependent on other factors, the wetting of the surface is a necessary condition in order to obtain adhesion between adherend and adhesive, but not the only one.

4 Core element 1: Classification of adhesively bonded joints according to safety requirements

4.1 General

An adhesively bonded structure within the meaning of this document is a material compound produced using adhesive(s) and designed mainly to transmit mechanical loads, its loadbearing function ensuring its reliability and fitness for use throughout the life cycle of the product. As part of a technical unit, the adhesively bonded joint in this assembly contributes to the strength and stability of the unit as a whole, or of part of the unit, or of a component. It is intended, in accordance with its requirement profile, to resist all stresses involved, irrespective of whether these are static, dynamic or a combination of both, and whether or not environmental effects are to be considered.

Requirements for the high-quality workmanship of those adhesively bonded joints shall be established by classifying them into safety classes. This classification into safety classes is based solely on the answer to the question of what happens if the adhesively bonded joint fails: What consequences can be expected for people and the environment and whether the consequences may occur directly or indirectly or how the probability of their occurrence is to be assessed? This question and its answer apply to every adhesively bonded joint in all areas of application in industry and trade for every adhesive used, regardless of:

— the strength and deformation properties of the adhesive used (i.e. all types of adhesives are covered, from low-modulus, highly resilient to high-modulus, very stiff adhesives);

— the solidification mechanism of the adhesive used (e.g. chemically curing, physically hardening, combined solidification mechanisms or adhesive-covered material such as adhesive tape); and

— the sector or purpose in which or for which the adhesively bonded assembly is to be used.

The safety classification of adhesively bonded joints in this document does not allow for any aspects such as their suitability for use with food, their fire resistance, compliance with pollution control

regulations or any stipulations regarding occupational safety or environmental protection, since these are covered in other standards, codes of practice or technical rules.

4.2 Definition of safety classes

The designer or the person dealing with the component concerned shall classify [in cooperation with the adhesive bonding coordinator (ABC) see Clause 5] each adhesively bonded joint into one of the following safety classes, taking into consideration the potential effects of adhesively bonded joint failure (see Table 1). The safety class of the relevant safety requirements to be met by an adhesively bonded joint shall be specified prior to its execution at the latest, or specified and documented by the adhesive bonding user in consultation with the Adhesive Bonding Coordinator (ABC see 5.1 and 5.3).

Table 1 illustrates the classification of adhesively bonded joints as a function of the relevant level of safety requirements.

Table 1 — Classification of adhesively bonded joints as a function of the level of safety requirements

S1 High level	**Failure of the adhesively bonded joint will**
	— directly or indirectly lead to an inevitable hazard to life or limb; — result in a failure of the function, the effect of which will mostly lead to an evident hazard to life or limb.
S2 Medium level	**Failure of the adhesively bonded joint**
	— can lead to a hazard to life or limb; — will result in a failure of the functionality, the effect of which will probably involve personal injury or result major environmental damage; — will result in a failure of the functionality, the effect of which will most likely involve major damage to property.
S3 Low level	**Failure of the adhesively bonded joint will result in a loss of functionality, the effect of which will probably:**
	— not involve personal injury or result in major environmental damage; — affect comfort or performance at the most; — not involve major damage to property.
S4 No level	**Failure of the adhesively bonded joint will result in a failure of functionality, the effect of which will:**
	— not, under foreseeable circumstances, involve personal injury or result in environmental damage; — only affect comfort or performance; — not involve damage to property.

An adhesively bonded joint can be assigned a higher safety class for economic, ecological and/or functional reasons, for example.

In particular applications, safety classes may already be specified in other existing International Standards, approvals or elsewhere. In cases of doubt, the highest possible class shall be assumed.

A component may include different types of adhesively bonded joints, which can be assigned to different safety classes, depending on the requirements specified.

Where an adhesively bonded joint is not to meet at least a low-level safety requirement, this adhesively bonded joint can be assigned to class S4.

All requirements of this document are for adhesively bonded joints classified as S1, S2 or S3. If an adhesive bonded joint is classified S4, this should be reasoned and to be documented but no more requirements of this document have to be fulfilled.

4.3 Documentation of the classification according to safety classes

The classification of the respective adhesively bonded joint shall be documented in writing by the responsible persons (see 4.2).

5 Core element 2: Adhesive bonding personnel (ABP)— Competences, knowledge and experiences

5.1 General

Depending on the classification of the safety requirements assigned to the respective adhesively bonded joint (see Clause 4), adhesive bonding work requires personnel with verifiable competence, knowledge and experience in adhesive bonding technology.

The user-company shall have sufficient competent personnel in accordance with the respective specified adhesive bonding requirements. This applies to all employees directly or indirectly involved in the adhesive bonding technology. The levels of competences, knowledge and experience required for the adhesive bonding personnel [(ABP) see Figure 1 as well as 5.2 and 5.3] are specified in 5.4.

In this context, adhesive bonding personnel (ABP) is the overarching term and includes all employees involved in the design, planning, manufacturing, quality assurance and maintenance/repair of adhesively bonded components and testing. This group consists of the following employees as shown in Figure 1.

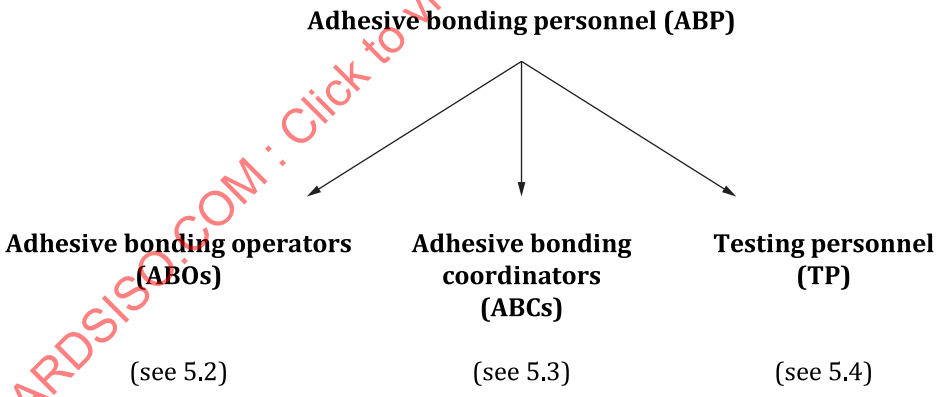


Figure 1 — Composition of the adhesive bonding personnel (ABP)

All adhesive bonding work carried out by subcontractors shall be carried out in the same manner in accordance with the requirements of this document. The subcontractor shall make the ABC available to supervise the adhesive bonding work.

For each adhesive bonding process, the necessary adhesive bonding competence of the personnel shall be determined. For all employees directly involved in adhesive bonding technology, it shall be ensured before the start of production that a competent personnel is available for all adhesive bonding work to be carried out.

For safety class S4 adhesively bonded joints (no safety requirements), this document does not impose any requirements on the adhesive bonding competence, knowledge and experience of the personnel. This can be defined in technical specifications or in the contract design outside this document (see 5.5, Table 4).

In addition, for safety class S1 and class S2 adhesive bonds, the following requirements shall be met (see 5.5, Table 4):

— the whole adhesive bonding process (from the start of surface treatment to the completion of the respective adhesively bonded joint) shall only be carried out by competent ABP as defined in 5.2 and 5.3;

— during adhesive bonding work, an ABC shall be accessible who is qualified and authorized to take any necessary action(s) in the case of any process deviations or a process released by the ABC exists that regulates the necessary action(s) to be taken if the ABC is not present on site;

— adhesive bonding process deviations and any action taken shall be documented.

5.2 Adhesive bonding operators (ABO)

5.2.1 General

The user-company shall have verifiable competent and trained personnel as adhesive bonding operators (ABOs), who are able to carry out adhesive bonding work processes independently and properly.

5.2.2 Functions

The ABOs in the company are the persons who independently and professionally carry out the adhesive bonding processes for the manufacture, maintenance or repair of components according to recognized work instructions.

5.2.3 Duties

The ABOs in the company have proven competence, knowledge and experience in adhesive bonding technology. This basis of understanding enables them to:

— understand the contents of approved work instructions in a technically competent way;

— classify their activities independently and professionally in the respective daily work context; and

— adapt their working methods accordingly.

5.2.4 Competences, knowledge and experiences

In the case of class S1 and S2 adhesive bonds, all employees involved in adhesive bonding work shall have verifiable level 3 competences (see Tables 3 and 4/5.4 and 5.5 as well as Annex A for assistance).

Vocational training in adhesive bonding or sealing (e.g. carpenter, floor layer, and upholsterer) can be accepted and documented by the ABC (see 5.3) as evidence of sufficient knowledge if adhesive bonding work is carried out in these areas. Participation in product training courses does not constitute sufficient proof.

The ABC is responsible for confirming the competence of the ABP for Class S3 adhesive bonds. The prerequisite is that ABC can prove that they have at least level 2 competence (see Tables 3 and 4 as well as for assistance A.1). The ABC shall justify the qualification of the adhesive bonding operators (ABOs).

The ABOs shall participate in verifiable regular (internal or external) training courses at intervals not exceeding two years, whereby it is the task of the ABC to decide on the scope and content of these training courses (see 5.4.2.5).

The competences, knowledge and experiences for ABO level 3 are defined in 5.4.2.4, and - both for assistance - Table A.1 as well as in A.3.

5.3 Adhesive bonding coordinator (ABC)

5.3.1 General

The adhesive bonding supervision is the responsibility of the user-company. In the user-company, one or more persons, depending on the extent of the adhesive bonding and the size of the user-company shall perform the adhesive bonding supervision.

However, the user-company shall instruct at least one ABC if at least class S3 adhesively bonded joints are dimensioned, planned, manufactured, commissioned, maintained or repaired.

The designation shall be carried out and documented by a leading or legitimate person.

If several persons have been designated as ABCs, the user-company can designate one ABC as the responsible adhesive bonding coordinator (rABC) who is authorized to coordinate all operations associated with adhesive bonding work in the various manufacturing areas.

Where a number of persons have been charged as ABCs, the tasks, scope of responsibility and interfaces shall be specified for each ABC separately.

In any case, the user-company shall organize a deputy regulation for each individual ABC or the rABC. If no equal deputy is appointed for the individual ABC or the rABC, it shall be ensured that no adhesive bonding-related decisions are made in the absence of the corresponding ABC.

The ABC shall not also be charged with adhesive bonding work as an ABO.

5.3.2 Functions

The ABC has the function of responsible adhesive bonding development, planning and process organization and execution. In addition, the person is responsible for supervising the adhesive bonding processes and all associated activities. This person is the appointed leader of all adhesive bonding processes (pre-, in-, post-production) including their release. The ABC thus has the appropriate decision-making authority with regard to the adhesive bonding technology in the company and is independent of operational, economic and time restrictions. For this reason, only those employees are appointed as ABCs who are in a position to:

— take a holistic and technically correct view of the adhesive bonding processes, i.e. from the idea to planning and execution to maintenance/repair and disposal; and

— perform the respective tasks and duties in accordance with this document without restriction.

5.3.3 Duties

During the adhesive bonding process, all special requirements for the adhesively bonded joint shall be taken into account. This shall be ensured for all relevant areas of the user-company's works. This includes, among other things:

— the development of the adhesively bonded joint including the design and constructional layout of the adhesively bonded joint as well as the design of the adhesive bonding process;

— the implementation of the adhesive bonding process in production;

— the consideration of reparability;

— purchasing as well as sales;

— assembly and

— subcontracting.

The main duties of the ABC are summarized in Table 2.

Table 2 — Duties of adhesive bonding coordinators (ABCs/examples)

Item no.	Description of duty
1	**Checking the contractual provisions** — Checking the suitability of the company which accepts the order for adhesive bonding and associated work.
2	**Checking the construction** — Conformance with relevant adhesive bonding standards, codes of practice and instruction sheets; — Analysis of stresses; — Design of adhesive bonds considering the construction requirements; — Specifying the adhesive bonding system; — Specifying adherends in cooperation with the responsible design engineer; — Accessibility for adhesive bonding; — Analysis of stress resistance of adhesive bonds. — Design of gap between adherends
3	**Checking the verification of adhesive bonds as specified in Clause 6**
4	**Checking storage and transport of adherends and other adhesive bonding system components** — Delivery and transport conditions; — Marking, storage, in-house transport and handling; — Traceability.
5	**Checking production planning** — Drawings and part lists, specifications for adhesive bonding and other materials, auxiliary materials and equipment used; — Drawings and part lists, specifications for adhesive bonding system and other materials, auxiliary materials and equipment used; — Work and repair instructions, their adequacy and validation; — Any necessary adhesive bonding and clamping equipment required verifiable qualifications of ABO; — Work and assembly sequences for components required ambient conditions.
6	**Assessment of any imperfections, damage or faults**
7	**Checking the equipment** — Suitability of adhesive bonding equipment; — Compliance with required manufacturing conditions; — Provision, identification and handling of any auxiliary materials and equipment.
8	**Supervision of adhesive bonding work** — Preparatory work; — Adhesive bonding; — Curing/hardening (solidification); — Checking the ambient conditions, including upstream and downstream process parameters.

Table 2 *(continued)*

Item no.	Description of duty
9	**Checking the adhesive bonding process** — Verifying maintenance of manufacturing quality.
10	**Testing the adhesive bonds** — Visual examination; — Destructive and non-destructive testing; — Assessing adhesively bonded and sealed joints.
11	**Checking any sub-contractors** — Suitability in terms of staff qualification, availability of staff, equipment, manufacturing facilities and the adhesive bonding process.
12	**Documentation** — Preparing, drafting and retaining any necessary reports, including those of sub-contractors.

5.3.4 Competences

The minimum requirements for the technological competences, knowledge and experience in the adhesive bonding technology of the ABC(s) are laid down as mandatory in 5.5, Table 4. These are supplemented by Table 3 (see 5.4.1). Annex A describes the contents in detail for assistance.

ABCs shall regularly prove that they have maintained or expanded their competence, see 5.4.2.5.

If an ABC does not perform certain tasks, these tasks may be assigned to employees with the same or lower adhesive bonding competence. It is the task of the ABC to select those deputy employees, to check their competences and instruct them as to the work to be performed. All details of such an assignment shall be documented in detail (see Table 4).

5.3.5 Organizational integration of adhesive bonding coordination

Only those persons from either the user-company's staff or an external consultant shall be appointed as ABCs who are capable of performing their respective duties and responsibilities in accordance with this document without any restrictions. To this effect, they shall be conferred the necessary managerial authority and entrusted with the decision-making powers permitting them to act free of operational and temporal constraints.

Only persons that have the same (or higher) competences, and who have been appointed officially are entitled to act as deputies of ABC without any restriction.

The company owner, managing director, operations manager or production manager may be appointed as ABCs where small-scale adhesive bonding work and class S1, S2 and S3 adhesively bonded joints are involved. They may also be appointed as deputy coordinators.

Small-scale adhesive bonding work is understood to cover cases where not more than 50 adhesively bonded assemblies are manufactured within 12 months. This shall be done on the same site, for the same assembly and using the same adhesive bonding technique. If at least two assemblies differ in type, the scope of manufacture shall no longer be deemed small-scale.

The organizational chart of the user-company shall specify in writing the work areas and responsibilities of, and the relationship between all persons having a managerial, executive or supervisory function affecting the quality of adhesive bonding work. This applies in particular to:

— the duties of the ABC (the work areas and responsibilities shall be delineated where a number of coordinators are involved);

— work requiring the presence of the ABC;

— measures to be taken in the absence of the ABC (e.g. appointing deputies; specifying the adhesive bonding work that is permitted or prohibited; specifying the time when adhesive bonding work shall be stopped).

5.4 Levels of competences, knowledge and experiences for adhesive bonding personnel (ABP)

5.4.1 General

For the adhesive bonding personnel (ABP) consisting of ABCs and ABOs, this document defines three levels of competences, knowledge and experience across hierarchies (see Table 3):

Level 1: comprehensive (decision-making level);

Level 2: specific (supervision level);

Level 3: basic (execution level).

Table 3 — Levels of competences, knowledge and experience for adhesive bonding personnel

Level	Scope of competences, knowledge and experiences
1	**Comprehensive** technological competences, knowledge and experiences in adhesive bonding technology are fulfilled by the state of the art skills (see for assistance A.3.1: Explanation of comprehensive competences) and advanced skills (minimum one-year suitable experience in adhesive bonding technology).
2	**Specific** technological competences, knowledge and experiences in adhesive bonding technology are fulfilled by the state of the art skills (see for assistance A.3.2: Explanation of specific competences) and advanced skills (minimum one-year suitable experience in adhesive bonding technology).
3	**Basic** technological competences, knowledge and experiences in adhesive bonding technology are fulfilled by the state of the art skills (see for assistance A.3.3: Explanation of basic competences). The training and qualification of this level can be approved by ABC. In this case, the ABC has to define the qualification range.

5.4.2 Requirements for each level of competences, knowledge and experiences

5.4.2.1 General

The focus for the verification of competences, knowledge and experience is the same for all three levels of competence (see Table 3). The subject contents summarized in the main categories (see list below), which together represent the entire field of modern adhesive bonding technology according to the current state of knowledge, are included:

— adhesion and adhesive;

— materials as substrates/adherends;

— design (including durability, ageing, fatigue, and its evaluation);

— adhesive bonding process – pre-production;

— adhesive bonding process – in-production;

— adhesive bonding process – post-production;

— maintenance;

— testing and analysis;

— health and safety;

— quality management.

The three levels mentioned in Table 3 correspond in principle to the hierarchy levels/fields of activity of the adhesive activities in the user-company (level 1: decision-maker level/level 2: supervision level/ level 3 execution level). These three competence levels determine which technical contents (see 5.4.2.2 to 5.4.2.4 and, for assistance, Annex A) shall be demonstrably mastered and to what extent a certain competence is required for a certain scope of work depending on the safety class according to this document (see 5.5).

The individual contents for the verification of competences, knowledge and experience of each level according to the main subject content (see 5.4.2.2 to 5.4.2.4) is specified in detail in Annex A for assistance.

The assignment of each level to the respective scope of work is specified in 5.5.

The minimum requirements for the technological competences, knowledge and experiences in adhesive bonding technology for the ABC and their deputies are shown in 5.5/Table 4.

For processes that can be assigned to in-production or post-production (see Introduction), the minimum number of employees with appropriate and verifiable competence shall be two, for example, an ABO and an ABC (see 5.5/Table 4 for the description of the competence level).

If necessary, a deputy ABC delegation shall be done in a suitable and traceable manner.

5.4.2.2 Level 1: Comprehensive

Comprehensive technological competences, knowledge application, practical application and experiences in adhesive bonding technology include the ability to supervise the whole spectrum of adhesive bonding work in the pre-production, in-production and post-production (see Introduction and Scope), that means from product development to production and on maintenance and repair activities. For correct technical application of adhesive bonding technology, these comprehensive competences require interdisciplinary thought, responsible decision-making and actions, as well as being able to oversee and take account of the entire product life cycle in a responsible way. These competences make persons comprehensively able to take on the tasks and responsibilities of the ABC in a company.

Comprehensive technological competences, knowledge application, practical application and experiences in adhesive bonding technology are defined in A.3.1 for assistance.

5.4.2.3 Level 2: Specific

Specific technological competences, knowledge application, practical application and experiences in adhesive bonding technology include the ability to prepare work instructions and supervise ABO and other adhesive bonding employees on theoretical and practical matters relating to adhesive bonding. These competences include also the ability to plan, organize, and monitor adhesive bonding processes, monitor process parameters, and if necessary adjust them. Also included is the competence to identify irregularities in production processes, maintenance processes and repair processes, and respond accordingly. Specific technological competences, knowledge and experiences enable the persons in their certain area of responsibility in the pre-production, in-production and post-production to take on the tasks and responsibilities of the ABC in a company.

Specific technological competences, knowledge application, practical application and experiences in adhesive bonding technology are defined in A.3.2 for assistance.

5.4.2.4 Level 3: Basic

Basic technological competences, knowledge application, practical application and experiences in adhesive bonding technology include fundamental understanding of adhesive bonding, enabling the special aspects of adhesive bonding processes to be understood and taken account of in production, maintenance and repair. The relevant context and importance of work instructions hence are clear. Basic technological competences enable the staff to independently undertake adhesive bonding work in a technically competent way in the in-production and post-production according to the given work instructions and to give feedback if irregularities occur.

Basic technological competences, knowledge application, practical application and experiences in adhesive bonding technology are defined in A.3.3 for assistance A.3.

5.4.2.5 Further training

The ABCs shall undergo further training at least every two years through measures (e.g. participation in adhesive bonding conferences, seminars or something like that) taken by providers who are legally and economically independent of the user-company. In-house training provided by the company's own personnel and product training shall not be considered training for ABCs for the purposes of this document.

At least every two years, ABOs shall also participate in further training measures. These measures can be held internally or externally. The content and duration of these courses shall be determined in consultation with the ABC.

Each further training measure shall be documented (such as date, duration, content, training documents, participants).

5.5 Assignment of the three competence levels to the safety classes depending on the respective scope of work — Correlation of the core elements

The level of technological competences, knowledge and experiences in adhesive bonding technology (see Table 3) is related to the safety class (see Table 1) of the adhesively bonded joints as well as to the scope of work outlined in Table 4.

Table 4 — Minimum requirements regarding the technological competences, knowledge and experiences in adhesive bonding technology for the adhesive bonding coordinators (ABCs) and deputies

Scope of work	Comments	Class S1	Class S2		Class S3	Class S4
Release of development-phase (pre-production) product and process designing		Level 1	Level 1 for product design *with* calculation/ validation	Level 2 for products *without* calculation/ validation	Level 2	to be defined by the user-company
Supervision of production/ manufacturing (in-production and maintenance/ repair (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

Table 4 *(continued)*

Scope of work	Comments	Class S1	Class S2	Class S3	Class S4
Involvement of ABC in purchase, sales, assembly and sub-contracting of adhesively bonded components and adhesive bonding work	The supply chain shall be a closed loop in a traceable way to ensure that every contract partner has the necessary competences	Level 2	Level 2	to be defined in the technical specifications	to be defined by the user-company

5.6 Comparability of competences, knowledge and experience

Within the three core elements of this document (see Clauses 4, 5 and 6), the competence, knowledge and experience of the personnel for adhesive bonding (core element 2) play the key role. The professional planning and execution of the adhesive bonding technology and the testing of adhesively bonded joints (see Clause 6) are based on this core element 2.

In order to do justice to this special significance, the requirements of this document regarding the competences, knowledge and experience of the personnel involved in adhesive bonding are defined by describing the required adhesive bonding competences, differentiating between comprehensive competences (see 5.4.2.2), specific competences (see 5.4.2.3) and basic competences (see 5.4.2.4).

In order to make the quality of adhesive bonded joints comparable at international level with the claim defined in the introduction, this document requires reliable comparability of the competences, knowledge and experience of the personnel involved in adhesive bonding and its processes at all levels.

NOTE In order to document expert competences to customers, clients, authorities, approval bodies and other interested parties with a maximum of security, ISO/IEC 17024 opens up a possibility of comparability of the proof of competence on national and international level.

5.7 Monitoring, inspection and testing personnel

The user-company shall have sufficient competent staff for the planning and execution of monitoring, quality control, testing and inspection of adhesive bonding work, in accordance with the requirements specified. As a rule, the evaluation of test results shall be the ABC's responsibility.

NOTE Personnel certificated to ISO 9712 is considered adequate.

6 Core element 3: Design and verification of adhesively bonded joints

6.1 General

The functional capability of an adhesively bonded joint is achieved if all requirements specified are satisfied. This will be ensured only if all of the following aspects are coordinated and are adequately dealt with giving due considerations to the requirements.

NOTE A detailed description is given in Annexes B to F.

6.2 Assignment to safety classes

Each adhesively bonded joint shall be assigned to a safety class in accordance with any potential consequences of failure in terms of safety, which in this document are fixed in 4.1/Table 1. The safety class shall be specified and documented in consultation with the ABC.

6.3 Requirements to be met by the adhesively bonded joints

The requirements to be met by the adhesively bonded joints shall be established and, in consultation with the ABC, documented in all organizational departments.

In addition, for safety class S1 and class S2 adhesively bonded joints, the following requirements shall be met:

— a procedure shall be developed and documented which ensures that requirements from all departments concerned are established;

— the requirements established shall be documented (e.g. in a list of specifications);

— proof shall be provided that the ABC has checked the requirements relating to the adhesively bonded joint.

NOTE The subjects, which are to be considered for the creation of a list of requirements, are listed in Annexes B and D.

6.4 Design of adhesively bonded joints

The size of adhesive bonding surfaces, their location, the distribution and the dimensions of the adhesive between adherends after solidification of the adhesive shall be specified and documented.

In addition, for safety class S1 and class S2 adhesively bonded joints, the following requirements shall be met:

— the joint tolerances shall be specified;

— conformance with the minimum or maximum adhesive bond line thickness shall be ensured;

— the relative position of adherends shall be clearly specified and shall be tolerances specified;

— tolerances shall be specified as a function of the requirements to be met by the adhesive system and the component or overall structure.

NOTE 1 Examples of design principles are described in in ISO 15785.

NOTE 2 A comprehensive adhesive bonding design guideline is included in Annex C.

6.5 Adherends

The properties of adherends and their as-delivered condition shall be specified.

In addition, for safety class S1 and class S2 adhesively bonded joints, the following requirement shall be met:

— the design of adherends, in particular their behaviour under the expected stresses, shall be specified and documented so as to permit them to be reproducibly manufactured.

6.6 Adhesive

The type of adhesive, together with its components, its field of application and place of use shall be specified and recorded.

NOTE The criteria for choosing an adhesive bonding system are described in Annex D. The requirements to be defined and specified (see Annex B) form the basis of the adhesive selection.

6.7 Surface treatment

The surface treatment, with all its stages, the materials used, place of use and working sequence shall be specified and recorded.

6.8 Factors affecting the adhesive bonding process

All factors affecting the adhesive bonding process (e.g. ambient conditions, processing times, stresses involved in the manufacturing process,) shall be established in cooperation with the ABC and the process design department and recorded.

6.9 Verification

6.9.1 General

Verification is a procedure intended to provide evidence that an assembly or a component complies with the requirements.

For safety class S1 and class S2 adhesively bonded joints, at least one of the following methods of verification shall be applied:

1) providing proof that stresses are lower than the stress resistance;

2) assembly/component testing;

3) documented experience;

4) combination of methods 1 to 3.

Verification shall cover not only the strength or stability under service conditions. It shall also include aspects such as adhesion, chemical resistance and stresses during manufacture.

6.9.2 Method 1 — Load in use < maximum load capacity

6.9.2.1 General

A safety factor shall be specified based on the quality of information obtained regarding load and load capacity; this shall be documented in a transparent way. Where laboratory values are used for assessing the adhesively bonded joint, proof shall specify that these results were obtained under real manufacturing conditions (process validation).

In addition, for safety class S1 adhesively bonded joints, the following requirement shall be met.

Process validation shall be repeated throughout the period of manufacture at reasonable, specified intervals, using suitable methods. These measures and their scope shall be specified and documented by the ABC.

6.9.2.2 Load

Loads can be derived from the list of specifications. They shall be determined by testing or calculation, or taken from standards or empirical data, or using a combination of these. Loads shall always take into consideration maximum values, exposure times, ambient conditions and any possible combined effects. Statistically substantiated information on the quality, intensity, duration and frequency of stresses throughout the lifecycle shall be obtained. The method by which such information was obtained shall be transparent and shall be documented.

6.9.2.3 Load capacity

The load capacity of adhesively bonded joints shall only be determined by testing. Tests shall be performed using samples, test components or an actual component as in service. Unless otherwise explicitly specified, adhesively bonded joints shall show cohesive failure in the case of destructive testing. Substrate failure shall be considered separately. If testing is not carried out on an actual assembly as in service, and if testing is not carried out under actual conditions, evidence shall be provided in a transparent way that deviations from the service conditions (e.g. accelerated ageing, testing agents used, and combinations of agents) are suitable for qualifying the adhesively bonded joint for the intended usage. Test results shall always be adequately evaluated statistically. The parameters determined shall be characteristic values with a specified survival probability. Data (e.g. test methods, results) shall be obtained in a transparent way, and shall be recorded.

6.9.3 Method 2 — Component testing

Component testing 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 comparable in terms of their effect on the adhesively bonded joint, proof of which shall be provided. When testing partial systems, the interaction between these and the system as a whole shall be considered and verified 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 adhesively bonded joint, 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.

6.9.4 Method 3 — Documented experience

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

6.9.5 Method 4 — Combination of methods 1 to 3

If the verification is affected by combining the above methods, it shall 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. when comparing test results with pass/fail criteria). The procedure shall be documented in a transparent way.

NOTE A verification guideline is included in Annex C.

7 Drafting contracts and subcontracting (outsourcing)

7.1 General

It is the responsibility of the company awarding the contract to check compliance with the terms of the contract with the provisions laid down by the customer and the internal guidelines of the user-company itself. It shall be ensured that all information required for the execution of the work is available before the start of the work.

The company accepting the contract shall demonstrate the ability to meet the contractual requirements for adhesively bonded constructions by establishing a quality plan including materials, methods, work instructions, inspection and quality assurance procedures (QA).

The company shall be aware of applicable national and international standards for definition, processing, inspection and testing procedures. Where standards are not available, the company

that accepts the order shall specify suitable procedures and methods allowing compliance with the contractual requirements. The company shall also be aware of national statutory obligations to health and safety requirements and environmental protection measures.

The company that accepts the order confirms to the company that places the order that all adhesive bonding work will be done in conformance with the contractual provisions. The company that accepts the order, in his/her own interest, shall identify any differences between the contractual provisions and any prior documentation, and inform the client about any modifications to the program, costs and workmanship that may result. The client shall ensure that all relevant information is made available.

The contractual provisions can refer to:

— required application standards, and any supplementary specifications;

— specifications for the adhesive bonding work to be done;

— details regarding the material and surface characteristics of the adherends;

— specifications regarding any surface treatment;

— quality documentation agreed with the client;

— specifications for the adhesive bonding technique to be used;

— specifications for testing, test methods;

— specifications for equipment to be used;

— approach regarding approval of the adhesive bonding technique to be used;

— recognition of verifiable staff qualifications;

— types, marking and/or traceability of adhesives and auxiliary materials, for example, and details of adhesive bonding work;

— provisions for quality control, any additional commissioning of an impartial test house;

— any other adhesive bonding requirements, e.g. purity of abrasives, temperature and/or humidity;

— ambient conditions on site affecting adhesive bonding work, e.g. a very low ambient temperature or any restrictions regarding surface treatment;

— any subcontracting permitted;

— measures to be taken in cases of non-conformity.

Where, in the course of adhesive bonding operations, there are organizational changes, for example, with respect to staff or equipment, it shall be checked whether such changes will affect quality. If so, any necessary measures are to be taken and are to be set down in the contract.

In addition, for safety class S1 and class S2 adhesively bonded joints, the following requirement shall be met.

— Any contractual check by which the order is accepted with regard to process steps that require special knowledge shall be documented.

7.2 Subcontracting (Outsourcing)

7.2.1 General

If an adhesive user intends to outsource or transfer the work to an external company (e.g. for adhesive bonding, destructive or non-destructive testing), the external company carries out the adhesive

bonding work in accordance with this document as an external service provider (subcontractor). As a rule, all requirements for the product shall be met, regardless of who performs which services.

It shall be ensured that the external service provider (subcontractor), who shall be able to fulfil these requirements, has been provided with all necessary documents and requirements, regardless of whether it is a service or an adhesively bonded product. They shall contain all relevant data from the contract and design review. Additional requirements shall be specified if design aspects of the structure are to be outsourced.

In most cases, the result of adhesive work cannot be verified non-destructively, it is the responsibility of the client to ensure that the processes at the external service provider's (subcontractor's) plant comply with the requirements effectively. This makes it necessary for external service providers (subcontractors) to conform with the relevant requirements of this document.

The client obliges the external service providers (subcontractors) to submit a quality plan as well as the records and documentation of their work specified by the client.

The client shall ensure that the external service providers (subcontractors) commissioned can fulfil the quality requirements of the contract.

In the case of subcontracting, the deputy ABC shall have at least level 3 qualification for class S1 and S2.

In case of subcontracting, an external ABC of the contracting company may not work for or be employed by subcontracting party.

7.2.2 Deciding on subcontracting

The decision as to whether any work is to be subcontracted, and the extent of any subcontracting shall be made in a transparent way.

In addition, for safety class S1 and class S2 adhesive bonds, the following requirements shall be met:

— the decision-making process shall involve the ABC;

— the decision shall be approved following a specified procedure;

— the approval shall be documented.

7.2.3 Details and documentation of procurement

The scope of the provided service shall be described correctly, completely, clearly and to be easy to understand.

All requirements to be fulfilled within the scope of work or services shall be established. The above description and the requirements shall be documented.

7.2.4 Selection of external service provider (subcontractor/supplier) and contracting

A suitable external service provider (subcontractor/supplier) shall be selected in accordance with the scope of work or service to be provided and the requirements to be satisfied.

Supplier and customer shall have reached agreement on a contract.

In addition, for safety class S1 and class S2 adhesive bonds, the following requirements shall be met:

— Changes to the documentation shall be subject to agreement between both parties and be clearly identified;

— External service provider (subcontractors/suppliers) shall be selected with the involvement of the ABC.

7.2.5 Management of external service providers (subcontractors/suppliers)

For safety class S1 and class S2 adhesive bonds, the following requirements shall be met

— Measures for monitoring of external service providers (subcontractors/suppliers) at product and process levels shall be drawn up and implemented. Their planning and implementation shall be documented.

— Design and implementation work shall involve the ABC.

8 Workmanship

8.1 General

Insofar as this applies to the respective process and is appropriate within the framework of the respective safety class, adhesively bonded joints shall be planned and executed in accordance with the following requirements.

The design of the adhesive bonding process planning and the adhesive bonding process execution shall be carried out such that it is guaranteed the process sequence is safe, reproducible and robust. Important criteria for the design and execution of adhesive bonding processes, especially for adhesive bonding with increased safety requirements (classes S1 and S2) are listed in this clause.

It shall be ensured that the adhesive bonding process is integrated into the overall production process, taking into account the operational conditions and the requirements of the process (see 8.2.1).

The following clauses provide a comparatively comprehensive overview, but more detailed requirements for the process shall be described by the user. This applies to each subclause.

All documents shall be prepared with the involvement of the ABC.

8.2 General process requirements

8.2.1 Production planning

The user-company shall carry out an adequate production planning compatible with the facilities described below and with the following points. This shall include:

— specification of the sequence by which the structure shall be manufactured, e.g. single parts, sub-assemblies, and the order of subsequent final assembly;

— identification of the adhesive bonding and associated processes required to manufacture the structure, and reference to the appropriate adhesive bonding procedure specification;

— specification of inspection and testing procedures, including the involvement of any independent inspection body.

8.2.2 Process design

8.2.2.1 General

The process design involves specifying the adhesive bonding process to ensure that the requirements to be met by the product or process are complied with in an efficient and reproducible way.

The requirements derive from:

— provisions associated with the adhesive bonding technique;

— customer requirements (e.g. as regards certification, documentation);

— structural requirements;

— occupational safety, health and environmental protection;

— legal requirements;

— in-house guidelines.

The following shall be considered when designing an adhesive bonding process:

— the requirements to be met by the manufacturing process shall be established.

In addition, for safety class S1 and class S2 adhesive bonds, the following requirements shall be met:

— the process shall be documented;

— the documentation shall be checked by the ABC;

— if the company uses a design from the company that places the production order or from any other company:

  — the planning documents shall be checked by the company carrying out the production order to ensure that all relevant requirements in accordance with this standard are fulfilled (e.g. classification, dimensions, tolerances, approvals);

  — the company is able to produce this part under the requirements of this document;

  — the production in the company that executes the order is released by the ABC.

8.2.2.2 Adhesive bonding as part of the overall production process

It shall be ensured that the adhesive bonding process is sensibly integrated into the overall production process, taking into account the operational conditions and the requirements of the process. The point in time in the overall production process at which adhesive bonding shall be carried out shall be specified and documented.

In addition, for safety class S1 and class S2 adhesive bonds, the following requirement shall be met:

— moving the adhesive bonding process to a different point in time requires the ABC's consent.

8.2.2.3 Work sequence and production technology

The steps of the adhesive bonding process and their sequence as well as the manufacturing technology used (e.g. tools, degree of automation) shall be defined.

In addition, for safety class S1 and class S2 adhesive bonds, the following requirements shall be met:

— work sequence and production technology used, and the relevant tests (process, product) shall be documented;

— proof of suitability of the manufacturing technology selected shall be provided. This proof can be based on experience (the transferability and applicability shall be demonstrated) or take the form of proof of capability (e.g. machine capability test, process capability test);

— specified type, scope and time of the process validation shall be complied with;

— the process of decision-making shall be documented.

8.2.3 Planning the use of production aids and tools

The use of any necessary production aids and tools shall be planned and their availability at the start of production shall be ensured (even after modifications to the process or product).

In addition, for safety class S1 and class S2 adhesive bonds, the following requirements shall be met:

— production aids and tools specific to adhesive bonding shall be documented for each particular adhesive bonding process;

— requirements for production aids and tools shall be specified and their suitability shall be demonstrated;

— their proper functioning throughout the manufacturing process, which also applies to automated manufacturing, shall be ensured.

8.2.4 Production documents

For each adhesive bonding process, documents (see Annex H) shall be prepared or be available which describe the details of work to the ABP. Design documents can also be used as production documents.

Production documents are to provide all information relevant to adhesive bonding work, as detailed above. These documents shall be up-to-date, correct, controlled, complete, clear and easy for the ABP to understand. It shall be ensured that the ABP receive all information required to make, in a reproducible manner, an adhesive bond meeting the requirements.

Production documents relating to adhesive bonding work shall be released by the ABC.

In addition, for safety class S1 and class S2 adhesive bonds, the following requirements shall be met:

— where the production process is automated, the parameters of the equipment relevant to adhesive bonding shall be defined, monitored and documented;

— processes shall be documented in order to ensure traceability (see 8.4.4);

— all quality-related steps shall be documented and the records kept on file.

The documentation for safety class S1 and class S2 adhesive bonds shall include at least the following:

— date and time;

— ambient conditions where relevant to adhesive bonding work;

— process parameters;

— adhesive bonding system: products, batches, expiry dates;

— identification of components and adherends;

— signature/identification of ABO;

— description of action taken in the case of process deviations (to be approved by the ABC).

8.2.5 Process approval

For safety class S1 adhesive bonds, the following requirements shall be met:

— the release shall be documented in a transparent way.

8.2.6 Transport, storage and logistics for adhesives, auxiliary materials and adherends

8.2.6.1 General

Transport and storage conditions (e.g. temperature and humidity) that are technologically required shall be determined and adhered to depending on the size, shape and weight of the parts to be joined, transport devices (lifting beams, vacuum suction lifts, etc.) may have to be specified and used.

8.2.6.2 Incoming goods inspection

In the incoming goods inspection, goods are to be checked for correct marking, an adequate shelf-life, and containers visually inspected (e.g. for any damage). Where materials are subject to specific requirements (e.g. regarding the temperature), these shall be complied with.

In addition, for safety class S1 and class S2 adhesive bonds, the following requirement shall be met:

— the delivery conditions shall be known and be comprehensible.

8.2.6.3 Storage

Storage shall be in accordance with the manufacturer's instructions regarding temperature and relative humidity. It is also to be ensured that no adhesive or auxiliary materials are used if these have gone past their expiry date and they have not undergone any new check by the appropriate manufacturer with a view to extending their shelf-life. Such an extension shall be made in writing and be documented.

It shall be ensured that there is no contamination of adhesives, auxiliary materials and adherends by substances that adversely affect adhesion.

All adhesives, auxiliary materials, adherends and production aids/tools shall be marked to permit easy identification with respect to the manufacturing documents. The shelf-life of adhesives and auxiliary materials shall be recognizable at any time during manufacture. For traceability purposes, the date at which a container was opened for the first time shall be documented, as material inside can then age and become unusable more quickly than in the original sealed container.

The storage conditions shall be known with regards to possible adverse effects, including those on components (e.g. contamination of adhesive bonding surfaces).

In addition, for safety class S1 and class S2 adhesive bonds, the following requirement shall be met:

— a storage system shall be provided or there shall be documented instructions ensuring that no adhesives or auxiliary materials in stock have exceeded their expiry date.

In addition, for safety class S1 adhesive bonds, the following requirement shall be met:

— the storage conditions shall be documented.

8.2.6.4 In-company transport

During in-house transport, materials shall not be affected by adverse conditions (e.g. moisture, temperature, light, contamination).

8.2.6.5 Conditioning of materials

Materials and adherends needed for adhesive bonding shall be conditioned for an adequate period in accordance with the requirements specified.

8.2.7 Production environment

The production environment shall meet the requirements specified for the adhesive bonding process and be prepared to ensure correct adhesive bonding. This also includes ensuring the necessary environmental conditions such as temperature, humidity, lighting, cleanliness, access restrictions, exclusion of materials that impermissibly affect adhesion, air quality and air currents.

To achieve this, the following requirements shall be met:

— identification and marking of the workplace for adhesive bonding;

— observance and adherence to temperature limits for adhesive bonding work and avoidance of inadmissible temperature fluctuations;

— surface temperature of the adherend needs to be minimum 3 K above the determined dew point;

— observance and adherence to moisture limits for adhesive bonding work;

— documentation of measured temperature and humidity values during production;

— observation of air movement and avoidance of inadmissible draughts;

— avoidance of impermissible impurities (e.g. silicones, dust, aerosols);

— creation of sufficient lighting conditions and sufficient space.

In addition, the following requirements shall be met for safety classes S1 and S2 adhesives

— access of the working place only for authorised persons;

— all regulations for the working environment shall be documented;

— proof of compliance with the regulations shall be provided.

— in areas where adhesive bonding work is carried out, the use of forbidden substances that impair adhesion (e.g. silicones, PTFE spray) is only permitted with the consent of the ABC.

— it shall also be ensured that these substances are not accidentally spread (e.g. by the ventilation system or with the same tools).

NOTE ISO 8502-4 gives a procedure for the measurement of the dew point.

8.2.8 Materials

All materials shall be certified by the adhesives supplier as conforming to relevant and applicable standards, regulations or other agreed standards or shall otherwise be shown to conform to purchasing requirements.

Visual examination of materials shall be carried out to ensure conformity to purchasing requirements. The expiry dates of all adhesive, paint and primer materials shall be checked and recorded.

Any materials not conforming to requirements, either by being defective or otherwise unsuitable, shall be quarantined to prevent them entering the fabrication system and disposed in an appropriate manner.

All materials shall be stored in accordance with the material supplier's recommendations given in the product data and safety data sheets.

Documentation for each batch of material shall cover all the necessary requirements for inspection, recording, release for use, quarantine and storage. These documents shall be retained for record purposes and a recording system ensuring full traceability of materials shall be used.

8.2.9 Preparation of work stations and acclimatization of materials

In order to ensure correct adhesive bonding, workplaces and zones for conditioning parts and adhesives shall be prepared accordingly. The following requirements shall be met.

— Ensure conformance with the correct temperature limits for the acclimatization of adhesives, adhesive bonding agents as primers and other materials. Determine and observe minimum duration of acclimatization.

— Maintain technically permissible temperature tolerances during the adhesive bonding process.

— Select suitable tools and auxiliary materials (devices, platforms, pumps, lifting or handling devices, tapes, cleaning wipes, spacers, etc.) according to the process and make them available in sufficient quantities.

— Provide material at the production site. Materials and aids shall conform with the specifications in the work instructions.

— Materials and auxiliary materials shall be adapted to the process and shall be provided in sufficient quantities, such as:

  — documentation documents, pens;

  — tools, fixtures, platforms, lifting equipment;

  — personal protective equipment (e.g. suitable silicone and powder-free gloves);

  — barrier tape, warning notices, stickers (e.g. "Blocked", "Do not enter vehicle", "Do not move vehicle");

  — joined parts;

  — wipes for cleaning (disposable wipes, dust-free and low-lint, not contaminated);

  — cleaning agents;

  — adhesives, primers, adhesive tapes, sealants, smoothing agents;

  — dosing and application equipment aids: spatulas, spatulas, pistols, nozzles, cups, etc.;

  — measuring equipment such as scales, measuring tapes, callipers, watches, etc.;

  — fixing aids, templates;

  — spacers;

  — silicone-free skin protection, skin cleaning and care products.

8.2.10 Health and safety and environmental protection

The supplier instructions and safety data sheets for the correct use, and any subsequent disposal, of products shall be followed. If a deviation from the established procedures is found to be necessary, the fabricator shall consult with the adhesive supplier as to the suitability of the proposed changes to the procedures, prior to implementing such a deviation. Records of deviations shall be maintained.

8.2.11 Checking for fitting accuracy concerning shape, position and dimension

The following requirements shall be observed in order to ensure correct adhesive bonding.

— Suitable test and measurement procedures (order-accepting company/contractor or supplier of the parts) shall be used for checking fitting accuracy after the conditioning of adherends prior to the application of the adhesive.

— Any specified tolerances shall not be exceeded. There is no exception for this.

8.2.12 Checks prior to start of production

Before starting production, the following checks shall be carried out to ensure correct adhesive bonding:

— verification of the objective proof of competence of the bonding personnel;

— suitability of the adhesive bonding procedure;

— suitability of the adhesive bonding process;

— verification that the correct adhesives and auxiliary materials are present on the workspace and in sufficient quantity;

— verification of the expiry date and storage temperature. For resealable containers, the date on which the container was first opened or the date until which this product may be used after opening shall be documented and maintained, as material inside can then age and become unusable more quickly than in the original sealed container;

— testing of adhesives and auxiliary materials (tapes, cloths, etc.) during production for abnormal appearance, odour or consistency, also taking into account occupational health and safety regulations;

— identification of the parts and areas to be adhesively bonded and checking the adherends are correct and fit for purpose;

— measure environmental conditions as temperature, and, if necessary, relative humidity using suitable equipment.

8.2.13 Treatment of the adherend surfaces

Agents for, and methods of surface treatment (cleaners, abrasives, adhesion promoters, etc.) shall be validated and specified in the work instructions (see 8.3).

The relevant cleaning and surface treatment instructions shall be respected and the delay between surface treatment and adhesive bonding shall be validated and monitored; any deviation shall be presented and evaluated AT-145 by the ABC. Any deviation shall be documented.

8.2.13.1 Cleaning

The following list only provides an overview. In any case, it shall be noted that the cleaning methods are highly dependent on the process and adhesive and can change quickly with new developments.

— In consultation with the ABC, only those cleaning agents and procedures may be used which are adapted to the contaminations that occur.

— Flash off-times shall be specified and observed (e.g. diffusion and porosity shall also be taken into account).

— Cloths used for cleaning shall be replaced sufficiently often by fresh cloths.

— It shall be ensured that the cleaning agents are not contaminated.

— If aqueous detergents are used, sufficient rinsing and drying shall be carried out.

— The cleaning result shall be checked, e.g. visually, by rubbing with a clean white paper towel or by wetting test.

— If cleaning baths or steam degreasing systems are used, the cleaning agent shall be monitored and changed or prepared accordingly.

— Contamination that may have a negative effect on adhesion after cleaning shall be avoided.

8.2.13.2 Surface treatment

— Only grinding or blasting media that are sufficiently free of contamination may be used. If necessary, these shall be replaced by fresh material.

— When using baths, contamination shall be avoided. Contamination shall be detected in good time and the baths shall be replaced regularly.

— After any pickling, adherends shall be adequately rinsed and dried.

— The result of the pre-treatment is, e.g. visual, wetness check of sample adhesive bond shall be checked.

— When using methods such as flame treatment, fluorination or plasma activation, the specified process parameters and process times shall be complied with and monitored.

— The result of surface treatment shall be checked, e.g. by inspection (visual or others), a wetting test or by trial adhesive bonding.

— When using adhesion promoters, the supplier's specifications in the technical data sheet shall be strictly observed and implemented.

— Materials shall be applied to cover the surface completely and consistently, using suitable devices.

— Auxiliary materials (clothes, tissues, brushes, felts, etc.) shall be replaced at sufficiently short intervals.

8.2.14 Dosing, mixing and application

The adhesive user shall ensure that the correct procedures, raw materials and processes have been selected for the application, following the quality plan. This information shall be specified on the job history sheet, on separate work instruction sheets or in a combined document, provided all relevant information is available.

The adhesive data and safety data sheet shall be followed, together with any requirements detailed in the quality plan or work instruction sheets when using the specified adhesive.

In the case of adhesive films and pressure-sensitive adhesives, apply the tape, in accordance with the adhesive producer's instructions, to one of the mating surfaces, ensuring that no air is trapped. If any air is trapped, it shall be removed by cutting or piercing the tape.

In the case of paste adhesives, apply the adhesive as recommended by the adhesive producer. For two-component or multi-component adhesive systems, it is recommended that only integral static or dynamic mixing systems from pre-filled containers or cartridges be used to ensure accurate mixing ratios. To ensure good mixing, the homogeneity of the mix shall be checked by its visual appearance.

Hand weighing and hand mixing shall not be used.

Apply a uniform layer or bead of adhesive to each mating surface (or spray, swirl, multi-dot, roll-coating, and insert e.g. in every case or as recommended by the adhesive producer) to ensure a filled joint when the parts are mated.

Dosing, mixing and application processes shall be validated and specified in the work instructions (see 8.3). In certain applications, the use of suitable meter-mix devices is also possible.

The relevant dosing, mixing and application process instructions shall be followed; any deviation shall be presented and evaluated by the ABC. Any deviation shall be documented.

— In the case of two-component adhesives, the specified mixing ratio, mixing quantity and sufficient mixing performance shall be observed. If possible, the properties to detect sufficient mixing is to be specified (e.g. mixing time, colour, etc.).

— Contamination during product removal from the container shall be avoided and the container shall be closed again immediately.

— The specified application process shall be observed.

— The specified adhesive quantity, bead geometry and its position shall be observed.

— Inclusions of air (that can promote the accumulation of condensation) and foreign body shall be avoided.

— Only clean application aids shall be used.

— Processing times shall be compatible with the ambient conditions.

8.2.15 Inspection and testing during adhesive bonding and adhesive solidification

During the adhesive bonding process, the following shall be determined/inspected, and the results shall be recorded for both components and any test coupons required:

— the ambient temperature and humidity;

— the adherend pre-treatment quality (comparison against a standard);

— the adherend temperature;

— the adhesive temperature;

— mixing of the adhesive;

— application of the adhesive;

— part assembly/location;

— the application of pressure and the value of the pressure used, if relevant;

— adhesive squeeze-out at the joint edges;

— the adhesive glue-line temperature and the cure period;

— test coupon preparation/processing;

— the operator's identity.

More detailed requirements for the process shall be described by the user.

8.2.16 Joining the adherends

Ensure all protective foils are removed from the tape adhesive before joint closure. The joint shall be made directly after removal of the protective foil. Care shall be taken not to contaminate exposed adhesive or pre-treated surfaces.

Close the joint avoiding air entrapment and reverse movement of the adherends perpendicular to the plane of adhesive bond.

Tape adhesives do not allow for position adjustment after joint closure and any necessary re-positioning may require the joint to be reworked as specified in the quality plan.

Check the assembled joint for any gaps or adhesive disbonds around the periphery, reworking to quality plan requirements if necessary.

The processes of joining the adherends shall be validated and specified in the work instructions (see 8.3). More detailed requirements for the process shall be described by the user. The relevant process instructions on joining of the adherends shall be followed; any deviation shall be presented and evaluated by the ABC. Any deviation shall be documented.

— The specified dimensions and tolerances of adhesive bead shall be respected.

— The instructions regarding the adhesive bonding process (direction of adhesive bonding, speed, contact pressure, prevention of air bubbles, withdrawal of adhesive from adhesive bonding surface, etc.) shall be respected.

— The processing time shall be defined and respected.

8.2.17 Fixing

8.2.17.1 Fixing processes

The fixing processes shall be validated and specified in the work instructions (see 8.3).

The relevant fixing process instructions/procedures/descriptions shall be followed; any deviation shall be presented and evaluated by the ABC. Any deviation shall be documented.

— The specified fixing method shall be used (using a fixing tool where necessary).

— The adherends shall be fixed at the specified points only.

— The specified fixing pressure and time shall be maintained.

More detailed requirements for the process shall be described by the user.

8.2.17.2 Clamping and curing

After assembly, ensure intimate contact of all mating surfaces by application of pressure on the joint area. Apply the defined and validated compressive clamping load to the joint, and check the periphery for even adhesive squeeze-out if this is a requirement. A clamping device may be necessary rigid materials.

Joints shall not be loaded within the handling, or working, time specified by the adhesive producer, and any clamping device used shall be left in place for the specified time.

The type of clamping device (if any), the clamping load, the times at which the clamping load was applied and removed, and the operator's identity shall be recorded. More detailed requirements for the process shall be described by the user.

The joint shall be closed as soon as possible after adhesive application. Apply the recommended compressive clamping load to the joint, and check the periphery for even adhesive squeeze-out.

If gaps or voids are visible exceeding the size outlined in work instructions rework needs to be performed according to a work to be defined procedure.

Remake the joint and apply the clamping pressure. Check for joint edge squeeze-out and make an adhesive fillet on the joint edge with a suitable hand tool, removing excess adhesive.

The clamped joint shall be left for the time specified by the adhesive producer to generate handling strength (at specified ambient temperatures) or left until full adhesive strength is achieved. Adhesive producer's instructions will generally specify strength generation rates at given ambient temperatures.

Avoid any reverse movement of the adherends perpendicular to the plane of adhesive bond.

After the specified cure period, remove any clamping devices. Record the type of clamping device used, the times at which the clamping load was applied and removed and the operator's identity.

NOTE Pressure-sensitive tapes develop their full strength at times beyond the initial tack strength.

8.2.18 Solidification of the adhesive

The solidification processes of the adhesive shall be validated and specified in the work instructions (see 8.3).

The relevant solidification process instructions shall be followed; any deviation shall be presented and evaluated by the ABC. Any deviation shall be documented.

— The specified solidification method and associated conditions shall be used.

— During the solidification, the adhesively bonded joints - if necessary - shall be labelled. They shall be protected against impermissible loads.

— The total solidification time shall be defined and met in function of ambient conditions.

8.2.19 Inspection and testing of finished components

Following completion of the adhesive bonding process, including post-adhesive bonding operations, compliance with acceptance criteria detailed in the quality plan shall be verified. Appropriate inspection tests include:

— visual inspection;

— conformance with dimensional requirements as indicated by drawings;

— non-destructive testing;

— coupon testing;

— random destructive testing.

8.2.20 Packaging and transport of adhesively bonded components

The packaging and transport processes shall be validated and specified in the work instructions (see 8.3).

The relevant packaging and transport process instructions shall be followed; any deviation shall be presented and evaluated by the ABC. Any deviation shall be documented.

— Damage to adhesively bonded components shall be avoided during transport.

— If the solidification of the adhesive in the adhesively bonding joint is not fully finished, it shall be ensured that the required adhesive bonding conditions are met during packaging or transport/moving/handling.

— Avoid interactions between the packaging material and the possible emission products from the unsolidified adhesive.

8.3 Work instructions: minimum requirements

The adhesive bonding procedures shall indicate at least (depending on the specific applied adhesive bonding technology, compare Table 5) the following information:

— scope of the work instruction;

— reference documents including revision status

— environmental parameters (e.g. temperature, humidity, dew point temperature);

— temperature of adherends;

— revision and date;

— type of adherend;

— type of adhesive, cleaner and adhesion promotor;

— check and/or document batch number, expiration date of usage, opening date, etc.;

— specific conditioning of the adherends and the adhesive bonding materials before use;

— equipment, systems and/or tools, auxiliary substances;

— sequence of operations;

— surface treatment of the adherends;

— timing of application (open time, solidification time, pot life, skin formation time, etc.);

— personal protective equipment;

— executions of any preliminary and intermediate inspections/checks to be carried out during the realization of the adhesively bonded joint.

Description of measures [these may only be carried out in conjunction with an rABC or its deputy (rABC/d)] and the traceability of the process parameters and the adhesive bonding operators shall be documented at minimum for class S1 and S2. The documentation of the traceability shall be recorded in a separate report.

All procedures related to adhesively bonded joints shall be approved by ABC or deputies (ABC/d).

The quality-relevant steps in production for classes S1 and S2 shall always be documented as shown in Table 5 and kept for a certain time, to be defined at the beginning of each project.

Table 5 — Manufacturing/process documentation class S1 and S2

Manufacturing/process documentation (for class S1 and S2)	**Essential**	**If necessary**
Identification of the producer of adhesively bonded materials	x	
Identification of the work station	x	
Identification of measurement equipment (humidity, temperature)		x
Identification of the adherends or if not possible identification of the mounting position	x	
Identification of adhesive bonding products like adhesive, adhesion promotor or cleaner (e.g. name, batch size, expiry dates,)	x	
Identification of the work instructions	x	
Documentation of the following process parameters:		
— date	x	
— time		x
— temperature of the adherends		x
— temperature of the adhesive containers	x	
— ambient temperature		x
— humidity conditions	x	x
— dew point	x	
— flash of time (cleaner, adhesion promotor)		x
— processing time (wet life, pot life)		x
— fixation time	x	x
— solidification time (curing/hardening time)		
— checking of dimensions of adherends		
— result of the evaluation of the work samples		
— date/time of commissioning		
Identification of the adhesive bonding operator	x	

Table 5 *(continued)*

Manufacturing/process documentation (for class S1 and S2)	Essential	If necessary
In case of deviation involvement of ABC or deputy	x	

8.4 Process reliability

8.4.1 General

Proof of production reliability shall be provided by periodically preparing suitable Production-accompanying work samples as specified in 8.4.8 document, i.e. it shall be verified that adhesive bonds can be produced as described in the design and manufacturing documents in a reproducible manner.

Verification of production reliability involves the continuous checking of process parameters and documentation.

8.4.2 Quality planning

For safety class S1 and class S2 adhesive bonds, the following requirements shall be met:

— the adhesive bonding process as a whole shall be documented;

— times, objectives, scope, responsible persons, staff and procedures for quality planning shall be specified and documented;

— any quality measures to be taken shall be documented and shall become part of the production documents;

— quality measures shall be checked in consultation with the ABC.

8.4.3 Control of planning and manufacturing documents

Planning and production documents shall be controlled in accordance with the quality management system (QMS). In particular, it shall be ensured that all current production documents have been made available to the ABP member in charge at the time of adhesive bonding.

8.4.4 Process validation

Following the design stage, it shall be checked that the procedure specified will fully comply with the technical requirements, i.e. it shall be verified that the adhesive bonding process as designed is feasible in its entirety and that the product can be consistently manufactured in terms of quantity and quality as required by the client.

In addition, for safety class S1 and class S2 adhesive bonds, the following requirements shall be met:

— there shall be a preliminary check of all individual steps of the production process;

— adhesive bonding process data shall be determined and documented in accordance with the established procedure;

— results shall be substantiated by preparing production-accompanying work samples and by test records;

— for permanently maintaining production quality, tests are to be carried out during production. For process control purposes, the adhesive user-company shall demonstrate that adhesion and cohesion are adequate. It shall be the ABC's responsibility to specify the type, extent and time of such checks.

In doing this, due consideration shall be given to the interfaces between process stages (storage, transport, effect of any downtimes on the upstream and downstream stages).

The first adhesive bond shall be prepared with the assistance of the production planner and the ABC, due consideration being given here that the entire production process reflects the later series production. Appropriately trained experts may represent the ABC. The assistance shall be documented.

In addition, for safety class S1 adhesive bonds, the following requirements shall be met:

— it shall be checked by means of theoretical consideration or simulation of the adhesive bonding process whether the process stages are properly synchronized and the required output is ensured.

— at the start of production at the latest, proof shall be provided that the design parameters (strength, deformation characteristics) are complied with; this may also be done by component testing (see 6.9) or by testing production-accompanying work samples.

8.4.5 Production-accompanying work samples as proof of application quality

Production-accompanying work samples taken during production are an indispensable tool to prove that the required quality and consistency of the production process is maintained.

This applies in any case to adhesively bonded joints of classes S1 and S2. On the other hand, for adhesive bonds of classes, the possible production of production-accompanying work samples shall be contractually agreed by mutual consent, taking into account the technical sense and necessity.

Proof of compliance with the required quality, consistency and reproducibility of an adhesive production process is provided by production-accompanying work samples. These samples shall be manufactured during production under the same conditions as the actual adhesively bonded product. In this way, the adhesive user-company can check its adhesive bonding processes.

For this purpose, the user-companies shall ensure that the adhesively bonded production-accompanying work samples are designed in such a way that they allow conclusions to be drawn about the actual adhesively bonded product without any doubt. For this purpose, the production-accompanying work samples shall be produced as close to production as possible (original adherend materials, adhesive, surfaces, production-related adhesive bonding process, product-related design of the work samples). The type, size, frequency and sample area of the work samples shall be determined by the ABC during production planning and included in the test plan documents or other documents relevant to the adhesively bonded joint.

The number of production-accompanying work samples depends on the production volume and the classification of the adhesive bonds. The frequency of work-samples shall be increased at the start of a new production, when the process is modified or after disruption to the process for a prolonged period.

Such modifications to the process can be due to the following process changes of the:

— site of manufacture;

— adhesive bonding equipment directly impacting the adhesive bonding process (excluding disposable consumables);

— surface characteristics;

— materials used (e.g. adhesives, adhesion promotors, support, etc.);

— component supplier;

— adhesive bonding work station.

In the event that the work-sample tested does not satisfy the requirements, the ABC shall be informed. It shall be his/her responsibility to decide on the measures to be taken in respect of the functionality of all similar adhesive bonds. Test methods and acceptance criteria shall be defined by the ABC in the proof plan.

Suitable test methods can be:

— appropriate bead peel test as described in E.3.5;

— tensile lap-shear test as described in E.3.3;

— peel resistance test as described in E.3.4;

— Shore hardness test as described in ISO 48-4;

— random destructive test;

— non-destructive tests;

— other tests method (including internal tests methods) validated by the ABC.

Test results for production-accompanying work-samples shall be documented in compliance with legal or contractual provisions.

8.4.6 Quality control of process reliability/traceability

Identification and traceability shall be maintained throughout the adhesive bonding/production process by suitable documented systems.

Annex H shows an example of a job history sheet, suitable for recording all relevant information and data; any other form of record documentation, in whole or part, shall be as extensive.

Keeping such records does not mean that other data and information records required by the quality plan, the adhesive user's general quality procedures or statutory requirements need not be kept.

For safety class S1 and class S2 adhesive bonds only, the following requirements shall be met:

— it shall be the ABC responsibility to confirm that the adhesive bonding work has been carried out in compliance with the requirements;

— the necessary action involved shall be specified by the ABC (e.g. by establishing quality control measures);

— it shall be the ABO responsibility to keep the adhesive bonding records.

The documentation (adhesive bonding records/see Annex I) shall include the following information:

— revision status;

— date and time;

— details of ambient conditions;

— process parameters;

— adhesive bonding system: products, batching, expiry dates;

— identification of components and adherends;

— signature or identity of the ABO;

— description of measures taken in the case of adhesive bonding process deviations (to be taken only in consultation with the ABC, who is to give his consent by signing);

— documentation of environmental conditions relevant to the adhesive bonding process;

— documenting or recording of adhesive bonding process (adhesive bonding records);

— signature of two persons;

— final check by an ABC (two-man rule).

8.4.7 Instruction of adhesive bonding personnel (ABP)

Using the production documents, the adhesive bonding personnel (ABP) involved in adhesive bonding work shall be instructed as to the individual processing steps and tests to be carried out prior to and after the start of production. It shall be ascertained that:

— the ABP have understood and accepted the instructions;

— the processing steps (sequence and duration of process stages) as designed are feasible;

— tolerances are realistic;

— production aids and tools fulfil the designed function;

— the ABP are adequately skilled.

In addition, for safety class S1 and class S2 adhesive bonds, the following requirement shall be met:

— each ABP member shall be instructed prior to the first bond he/she will make, and this shall be documented.

8.4.8 Post-adhesive bonding finishing

The user-company shall be responsible for the specification of post-adhesive bonding finishing. The processes and materials shall be compatible with the adherends; the surface conditions and the adhesive used, and shall be in accordance with any specifications detailed in the quality plan.

A record of any finishing operation shall be made.

8.5 Rework

In case of detection of imperfections in the adhesive bond after solidification, rework shall be carried out. This rework shall be done according to the instructions defined by the ABC and shall be documented in the same way as the normal production work.

8.6 Quality assurance

8.6.1 General

All adhesive bonding stages and all finished adhesively bonded joints shall be inspected to the agreed contractual requirement.

Documents for quality assurance shall be prepared for classes S1 and S2, with support of the ABC.

For class S3, the use of these documents can be agreed as required.

The quality assurance system applies to both new and reworked products.

8.6.2 Quality planning

In order to ensure conformity of the quality of components, processes and work-samples with the requirements specified in the design and manufacturing documents, testing in accordance with a testing plan (see Annex I) or comparable shall be carried out. At least one test method should be used that permits any deviations of the production process or the material characteristics to be established.

The items of the testing plan, the test instructions and the test report are listed in Annex I describing minimum requirements.

NOTE 1 Test methods are described in Annex E.

NOTE 2 Accelerating ageing tests are described in Annex F.

8.6.3 Quality inspection

8.6.3.1 General

The quality inspection includes the testing of components and work samples as well as process control according to the testing plan. When using test procedures, standardized procedures shall be used. These shall be validated for case in question.

8.6.3.2 Test methods

The following may be used as test methods (see Annex E):

a) non-destructive methods:

- visual check;
- tightness test;
- dye penetrant inspection;
- methods using ultrasound, radiation, electrical conductivity, etc.

b) destructive methods:

- tensile, shear, peel testing;
- fatigue testing;
- cyclic testing.

c) Accelerating ageing tests: see Annex F.

8.6.3.3 Verifying production consistency

Proof of production consistency shall be provided by periodically preparing suitable work-samples as specified in 8.4, i.e. it shall be verified that adhesive bonds can be produced as described in the design and manufacturing documents in a reproducible manner.

Verification of production consistency involves the continuous checking of process parameters and documentation.

8.6.4 Action in the case of deviations

Based on the evaluation of the test report, a decision shall be made as to the release of a product or any necessary corrective action. Corrective action may relate to a component, a process or the specifications in the design and manufacturing documentation.

Procedures shall be established to control the flow of information, decision-making channels and the behaviour of staff involved in the adhesive bonding process in the case of process disruption and deviations.

In addition, for safety class S1 and class S2 adhesive bonds, the following requirements shall be met:

— it shall be specified which form of process disturbance is to cause the adhesive bonding process to be disrupted;

— it shall also be specified under which conditions the adhesive bonding process may be restarted;

— all staff involved in the adhesive bonding process shall be duly instructed in the procedures;

— procedures and instructions shall be documented.

8.6.5 Monitoring of measuring and test equipment and of production aids and tools

8.6.5.1 Monitoring measuring equipment

Any measuring equipment used in the adhesive bonding process shall be monitored. This applies, in particular, to instruments for measuring the ambient temperature, the component temperature and humidity, balances required when using two-component adhesives, and equipment for measuring the radiant intensity where light curing is involved.

In addition, for safety class S1 and class S2 adhesive bonds, the following requirement shall be met:

— measuring equipment shall be calibrated at specified intervals.

8.6.5.2 Monitoring adhesive bonding equipment

Adhesive bonding equipment shall be monitored with respect to its function and cleanliness. This applies, in particular, to application devices and equipment used for curing the adhesive. Where equipment requires maintenance, this shall be done by verifiable competent ABP.

In addition, for safety class S1 and class S2 adhesive bonds, the following requirement shall be met:

— monitoring of the equipment and training of ABP shall be documented.

8.6.5.3 Monitoring test equipment

Proof shall be provided that all test equipment used in the adhesive bonding process is monitored. This applies, in particular, to testing machines, surface measuring instruments and analytical equipment.

In addition, for safety class S1 and class S2 adhesive bonds, the following requirements shall be met:

— test equipment shall be calibrated at specified intervals;

— proof shall be provided that the staff using the equipment have been trained.

8.6.6 Imperfections in adhesively bonded joints

8.6.6.1 Application-related imperfections

Any imperfections produced during manufacture or repair shall be assessed taken the application into consideration. An informative list of such imperfections and their causes is given in Annex G.

8.6.6.2 Decorative imperfections

Decorative imperfections that are those, which have no effect on the technical function of the adhesive bond can occur. A decision as to whether such imperfections are admissible should be made on a case-by-case basis.

NOTE Examples of non-decorative and decorative imperfections are described in Annex G.

8.6.7 Control of non-conforming products

A process shall be established to control non-conforming products.

In addition, for safety class S1, class S2 and class S3 adhesive bonds, the following requirements shall be met:

— there shall be a process for dealing with adhesives and auxiliary materials which have gone past their expiry date;

— this applies particularly in cases where the adhesive user seeks to extend the shelf-life.

8.6.8 Preventive and corrective action

A process shall be established that governs any preventive or corrective actions (e.g. where the adhesive composition or the surface condition of adhesive bonding surfaces changes, etc.).

9 Maintenance and repair

9.1 General

All maintenance and repair work on adhesively bonded parts shall be carried out to the agreed safety class, if the design is not changed. The proof of conformity shall be upheld.

Prior to adhesive bonding work, the:

— scope of work shall be defined;

— class shall be identified;

— documentation shall be completed.

Any deviation from documentation of the company that gives the order (e.g. drawing, bill of material, safety class, etc.) shall be justified. Verifications by analysis or testing in accordance with this document (see Clause 5, in particular) shall be made, where necessary.

If no previous information or documentation is available, requirements for maintenance work shall be specified so that the required technical condition is ensured for class S1 and S2.

User-companies that do not carry out adhesive bonding work during maintenance and repair are permitted to subcontract such work, where the workshop in which the adhesive bonding work is done shall meet the requirements of this document.

When companies that accept the order carry out maintenance/repair, they are permitted to perform such work at another site only if this is possible under the same conditions and if the same quality requirements can be fulfilled, whereas the workshop in which the adhesive bonding work is done shall meet the requirements of this document.

9.2 Planning of maintenance and repair

Where an adhesive bond to be made as part of maintenance work has not been classified, the responsible designer, together with the ABC, shall assign a safety class (see Table 1) to the adhesive bond.

The type of maintenance work concerned shall be defined prior to planning.

Prior to starting maintenance, it shall be checked whether the intended measures have already been planned. If not, the measures shall be planned (see 8.2.2).

In addition, for safety class S1 and class S2 adhesive bonds, the following requirements shall be met:

— if an adhesive bonding process to be used (using specified materials) has already been released, it shall be ensured that this process is applicable to the case in question;

— if a process (using materials still to be specified) shall be qualified for the first time with the support of the ABC, its suitability for the intended purpose shall be verified and documented (see 8.2.2);

— if an adhesive bond is made based on the parameters of a process already released, but with certain deviations for the new adhesive bond (e.g. adhesive bonding on an old bead using the same adhesive), any deviating stages shall first be approved;

— ideally, maintenance work shall be specified when approving a new design;

— given the fact that am adhesive bond mostly cannot be tested non-destructively, maintenance work shall be designed so that the serviceability of the adhesive bond is ensured;

— since the factual circumstances (e.g. adhesive bonding surfaces, adhesion, contamination) only becomes apparent during maintenance work, any possible alternatives shall be considered already at the design stage or a process shall be designed that ensures a reliable procedure at the time of work;

— in order to ensure a consistent quality of production, accompanying testing shall be carried out as follows:

  — the type, scope and time of testing are to be specified;

  — it shall be the designer's responsibility to decide, in consultation with the ABC, on the type, scope and time of testing;

  — the decision-making process shall be documented.

9.3 Maintenance and repair instructions

Maintenance and repair work on class S1 to class S3 shall be done based on written work instructions prepared for the class in question. Details of the work performed shall be documented for these classes. The validation of the instructions shall be checked by the ABC.

Instructions shall be drawn up for maintenance work, specifying the procedure to be followed by the ABO in adhesive bonding work.

In addition, for safety class S1 and class S2 adhesive bonds, the following requirements shall be met:

— it shall be the designer's responsibility to release the design of maintenance work, in consultation with the ABC;

— the release shall be documented in a transparent way.

9.4 Performing maintenance work/execution rules

Where the condition of surfaces is unknown, a known surface condition shall be achieved (e.g. by removing unknown coatings by grinding). If this is not possible, the safety level shall be ensured by employing additional joining methods.

In the case of a suspected failure, the condition of any inaccessible adhesive bond shall be evaluated by properly inspecting neighbouring zones or the component as a whole.

Any deformation of the body structure shall be avoided during exchange from adhesively bonded components.

Where maintenance work is done on sites outside the contractor's responsibility, the ABC of the company actually doing the work is to ensure that all necessary conditions are complied with prior to, during and after adhesive bonding work.

If the responsibility is to be defined in a different way (e.g. in a client-contractor relationship), this shall be contractually agreed. The person responsible shall have the qualifications in accordance with the requirements specified in this document for adhesive bonding work (see Clause 5).

In addition, for safety class S1 and class S2 adhesive bonds, the following requirement shall be met:

— staff charged to carry out maintenance adhesive bonding work shall have the Level 3 competence (see Clause 5) or similar qualifications which allow them to identify any anomalies specific to the particular adhesive bonding work (e.g. corrosion, voids, insufficient adhesion) and report these in accordance with the in-house procedures.

9.5 Documentation

Maintenance/repair activities require the following minimum information that shall be contained in a Maintenance/repair manual written by the company that has managed the design activities of the adhesively bonded parts. If such a manual is not provided, is no longer available or should be updated, the maintenance/repair company can create its own manual or modify the one was provided only after warranty period. In any case, the documentation shall include, as a minimum:

— catalogue of the adhesively bonded joints (e.g. drawing, bill of materials);

— instruction including surface preparation (cleaning), pre-treatment and post-treatment of the parts subject to maintenance inspection;

— operational repair procedures [including the list of the used adhesives with relative technical data sheet (TDS) and safety data sheet (SDS);

— necessary equipment and instrumentation;

— plan of the preliminary to final checks.

In the case of any change in the design of the joint, the maintenance/repair process shall follow the general workflow principle demonstrated in Annex C, Figure C.1.

For safety class S1 and class S2 adhesive bonds, the following requirement shall be met:

— the maintenance process shall be documented, at least reporting the data in the adhesive bonding records and the area concerned.

9.6 Sub-contracting

For sub-contractors this complete document, i.e. ISO 21368, shall be applicable.

Annex A
(informative)

Assistance for providing adhesive bonding technology competences

A.1 General

The essential competences in adhesive bonding technology are explained, the objective is to provide the user of this document with a framework to form the basis of harmonised training requirements. The framework provides a demonstrated way of developing and establishing a contemporary and comprehensive personnel qualification in adhesive bonding technology.

Table A.1 provides the general background to the skills required at each level and the associated learning objectives.

Table A.1 — Competence levels — Skills and duties with related learning objectives for each level

Level	Level Designation	Overarching, technology- and content-independent skills and duties	Overarching, technology- and content-independent learning objectives
1	Comprehensive	Interdisciplinary thinking, decision-making and acting, comprehension of the product life cycle, etc.	Evaluate, create and transfer technical knowledge to new circumstances.
2	Specific	Planning, organizing and controlling, adjusting process parameters, recognising and reacting to irregularities in production, maintenance and servicing processes etc.	Apply, analyse, understand and explain technical content.
3	Basic	Independent and competent execution of work instructions, classification of work instructions in situational contexts, recognition of irregularities and reporting them	Know and understand technical content.

NOTE 1 See concerning overarching, technology- and content-independent skills and duties for example 5.4.1/ Table 3 and 5.4.2.2 to 5.4.2.4.

NOTE 2 See concerning overarching, technology- and content-independent learning objectives examples of typical action verbs[52] [53] [54].

Learning objective level 1: transfer, develop, evaluate, decide, assess, select, etc.

Learning objective level 2: explain, determine, interpret, identify, compare, check, implement, etc.

Learning objective level 3: name, describe, understand, get to know, apply, perform, report, etc.

A.2 Supporting the acquisition and providing of competences for adhesive bonding personnel (ABP)

Clause A.2 offers a comprehensive, decades-long, internationally recognised and industry-accepted proposal for the professional and contemporary implementation of a target group-oriented qualification for employees in adhesive bonding technology (ABP). For each main content from 5.4.2.1, Table A.2 gives detailed target group-oriented instructions for linking the overarching competence levels from Table 3 with the technology and content-independent learning objective levels described in A.1. The adhesive bonding technology concretisation of this link is listed in detail in A.3 for each of the three

competence levels mentioned in Table 3. As a result of this target group orientation, the action verbs used (A.3.1 to A.3.3) in the context of this in-depth content are to be understood exclusively: They show the assignment of the in-depth content to the respective learning objective level by way of example.

Table A.2 — Subject contents concerning minimum technological competences for adhesive bonding processes including engineering, production, maintenance and repair

Minimum technological competences for adhesive bonding processes including engineering, production, maintenance and repair	**Level 1 (comprehensive)**	**Level 2 (specific)**	**Level 3 (basic)**
Subject content	detailed description of each subject content in A.2 clause number	detailed description of each subject content in A.2 clause number	detailed description of each subject content in A.2 clause number
Adhesion and adhesives	A.3.1.1	A.3.2.1	A.3.3.1
Materials as substrates/adherends)	A.3.1.2	A.3.2.2	A.3.3.2
Design (incl. durability, ageing, fatigue) and its validation	A.3.1.3 A.3.1.4	A.3.2.3 A.3.2.4	A.3.3.3 A.3.3.4
Adhesive bonding process – pre-production	A.3.1.5 A.3.1.8	A.3.2.5 A.3.2.8	A.3.3.5 A.3.3.8
Adhesive bonding process – in-production	A.3.1.5 A.3.1.8	A.3.2.5 A.3.2.8	A.3.3.5 A.3.3.8
Adhesive bonding process – post-production	A.3.1.5 A.3.1.8	A.3.2.5 A.3.2.8	A.3.3.5 A.3.3.8
Maintenance	A.3.1.9	A.3.2.9	A.3.3.9
Testing and analysis	A.3.1.6.1 A.3.1.6.2 A.3.1.6.3	A.3.2.6.	A.3.3.6
Health and safety	A.3.1.8	A.3.2.8	A.3.3.8
Quality management	A.3.1.7	A.3.2.7	A.3.3.7

A.3 Minimum technological competences for adhesive bonding processes – detailed definitions

A.3.1 Comprehensive: detailed definitions

A.3.1.1 Adhesion and adhesives

Detailed comprehensive competences, knowledge application, practical application and experiences according to 5.4.2.2, with respect to these subject contents, includes being able to:

— estimate adhesive bonding technology considering capabilities/pros and limitations/cons that are involved and compare it with other joining methods;

— describe and explain the main functions and the working principles of adhesive joints;

— define additional functions that may be taken over by adhesives;

— explain a “special quality management process” (see NOTE below) that can only be controlled by special process management as a general and transfer this to the adhesive bonding process;

— give a definition and to evaluate the concept of joint strength to characterize the performance of adhesively bonded joints;

— give definitions and explanations of following terms like atom, orbital, molecule, mole, molecular weight, monomer, polymer, prepolymer;

— name the different types of intermolecular and intramolecular interactions and (for covalent bonds and for the different types of physical interactions) to explain how they form and to interpret their properties with each other;

— describe composition and primary structures of polymers (homopolymers and copolymers, branched and crosslinked structures);

— describe secondary structures of polymers (amorphous structures, crystalline structures);

— know the different classes of plastics (thermoplastics, elastomers, thermosets, thermoplastic elastomers) and to describe and explain their characteristic structure and typical properties when exposed to elevated temperatures, organic solvents/water, mechanical loads;

— interpret the relationship between the structure of polymers and chain mobility;

— deduce information about the properties (esp. concerning macroscopic and microscopic deformation behaviour) of a polymer from knowledge of its structure;

— describe the concept of thermodynamics of processes (Free Enthalpy G, Enthalpy H, Entropy S, Free Energy F, Internal Energy U, thermodynamic equilibrium);

— explain and evaluate the torsion pendulum test and the results;

— describe the temperature dependence of chain mobility and of the mechanical behaviour of polymers (esp. of the storage modulus G') depending on the various thermal states for thermosets, elastomers, amorphous thermoplastics and semi-crystalline thermoplastics;

— name different criteria for the classification of adhesives and to give detailed classifications according to their chemical composition and their solidification mechanism;

— explain the general difference between physically hardening and chemically curing adhesives and to describe the principles of the mechanisms;

— assign adhesives to specific classes of physically hardening adhesives or polyreactions;

— explain the principal processing steps and conditions to heed for various adhesives and to know the consequences that may occur, if there are deviations;

— know the general adhesively bonded joint properties after solidification for the adhesives;

— know how to calculate equivalents to evaluate the mixing ratio of 2-component adhesives;

— describe the functions of fillers used in adhesive formulations;

— explain and apply the terms adhesion, phase and interphase, adhesion energy, joint strength, entropy, enthalpy, interfacial tension and interfacial energy (Gibb's thermodynamics), wetting, contact angle (Young equation);

— know about the bonds and interactions in and between condensed phases, to compare them with each other and to explain their formation and their relevance for adhesion (chemical bonds, physical interactions, electrical double layer);

— know about relevant properties of surfaces which affect adhesion and to describe the influences (wettability, surface structure, surface composition, contamination);

— predict the course of physical processes and chemical reactions in a system using thermodynamic parameters ($G = H - TS$ or $F = U - TS$, dependence of a process on ΔG and ΔF);

— describe the behaviour of polymers on inorganic and polymeric interfaces and the behaviour at interfaces in general, with and without specific interactions with the neighbouring phase (features of inorganic and polymeric interfaces (compatibility, positive and negative adsorption), special features of the orientation of polymer chains, their chain ends and side chains);

— name the different adhesion models/theories and describe the mechanisms they are based on (mechanical adhesion, specific adhesion (polarisation theory of adhesion, electrostatic theory of adhesion/EDL, diffusion theory of adhesion, thermodynamic adhesion models, chemical adhesion);

— develop, implement and inspect necessary measures in the practice concerning the long term-stable adhesion and the correct application of the adhesives.

NOTE An example is a process given to ISO 9001.

A.3.1.2 Materials as adherends

Detailed comprehensive competences, knowledge application, practical application and experiences according to 5.4.2.2, with respect to these subject content, includes being able to:

— describe polymers, materials (thermoplastics, thermosets, elastomers, thermoplastic elastomers), surface properties (polymer/polymer interactions, compatibility of polymers, surface tension, contaminations) and their estimation of adhesive bonding properties for use in practice;

— describe metallic materials (steels, galvanized steels, aluminium, internal structures of metallic materials, deformation mechanisms, hardening mechanisms, failure mechanisms, surface properties;

— describe glasses (soda-lime glass, internal structure, surface properties, gel layer);

— describe fibre reinforced plastics (FRPs) including glass fibre reinforced plastics (GFRPs) and carbon fibre reinforced plastics (CFRPs), composition and internal structure of FRPs, general properties compared with other materials, mechanical properties, anisotropy, surface properties (polymer/polymer interactions, compatibility of polymers, surface tension, contamination) and their estimation of adhesive bonding properties for use in practice;

— explain objectives of surface treatment for adhesive bonding technology (selection criteria for surface treatment methods: cleaning with aqueous cleaning agents, cleaning with solvent-containing cleaning agents, grinding, grit blasting, peel-ply (FRPs), etching/conversion methods, anodization, silicatisation (sand coating method, flame pyrolysis method), flame treatment, fluorination/oxyfluorination, AP plasma/Corona, LP plasma for fine-cleaning, activation, coating, VUV-Treatment, adhesion promotor);

— explain technical characteristics of the methods (the process steps and process parameters);

— describe physical and chemical principles of the methods;

— explain resulting changes to the surfaces/effects on the surfaces;

— describe fields of application/advantages and disadvantages compared among each other;

— explain and apply the definition of force, stress, strain and modulus and how they are correlated with each other, deformation behaviour of polymers [elastic deformation (Hooke's Law for tensile and shear loads, Poisson's ratio, correlation between E, G and ν], viscous deformation (with the special case "plastic deformation"), visco-elastic deformation, time-dependent behaviour, creep, influences on the deformation behaviour of polymers (esp. material, temperature, load rate, plasticising effects, modelling of the deformation behaviour using analogous models, rheological base elements (e.g. Hookean, Newtonian, St. Venant elements), rheological base element combinations (e.g. Maxwell model, Voigt-Kelvin model), behaviour of base elements and base element combinations during retardation and relaxation;

— select and implement the most suitable adherend material and its most suitable surface treatment method.

A.3.1.3 Construction and design

Detailed comprehensive competences, knowledge application, practical application and experiences according to 5.4.2.2, with respect to these subject content, includes being able to:

— apply fundamental principles of mechanics, stress, stress and strain, uniaxial and multiaxial, tensile stress, compressive stress, shear stress, strain, uniaxial and multiaxial, tensile strain, compression strain, shear strain, nominal stress and nominal strain, true stress and true strain, Hooke's Law, elastic constants, E-modulus, shear modulus, Poisson's ratio, shape change and volume change under hydrostatic pressure/tension, equivalent stress and equivalent strain (e.g. von Mises), stress distribution in an adhesively bonded lap joint when subjected to shear stress; influence of variation of overlap length, adhesive film thickness, stiffness of the adherends, calculation of stress and strain using examples, calculation of equivalent parameters using examples;

— explain the systematic methodical approach to product development:

  — planning phase: description of the task; list of requirements, concept phase (subsystems; function analysis; drafting of concepts), concept evaluation;

  — design phase: adherend material selection; design rules, principles, guidelines; adhesive selection, dimensioning;

  — production planning;

— draw up lists of requirements for adhesive bonding applications [main parameters, formal list of requirements (requirements and desires)];

— know the fundamental principles of design suitable for adhesively bonded joints;

— select adhesives for specific applications [compare the requirement profile for application with the property profiles of adhesives and with methods for determining missing data (qualification of adhesives), ranking of adhesives];

— describe methods for determining parameters for dimensioning approximately dimensioning of adhesively bonded joints by load analysis (nominal parameter approaches for low-modulus adhesives, analytical approaches for high-modulus adhesives, basics of finite element method (FEM), safety factors, design load value and load limit analysis (characteristic values, determination of knock down factors considering relevant influencing factors for the long-term behaviour of adhesively bonded joints (temperature, media, creep, fatigue, etc.), safety factors, load limit value;

— be familiar with capabilities and limits of the various calculation methods (nominal and analytical approaches, FEM analysis);

— analyse, to verify and to evaluate the structural design of adhesively bonded joints in components;

— describe basics of elementary mechanical joining processes (clinching, riveting (self-piercing rivets and blind rivets), parameters influencing the quality of mechanically joined components, hybrid joining: definition, influencing factors, typical combinations of with practical relevance, advantages of hybrid joining compared to the respective elementary joining methods, fixing method, sequence method;

— estimate with responsibility and implement the long term-stable use of adhesive bonding in each certain joining case.

A.3.1.4 Durability

Detailed comprehensive competences, knowledge application, practical application and experiences according to 5.4.2.2, with respect to these subject contents, includes being able to:

— describe ageing (definition, causes, consequences, internal ageing, ageing caused by mechanical stress, ageing caused by the effect of moisture and aggressive media, the accelerating effect of elevated temperature on ageing, photodegradation (principles of photooxidation and direct photodegradation, weathering (outdoor exposure), the "philosophy" of accelerated ageing in the laboratory;

— describe corrosion in aqueous environments (requirements, cathodic and anodic reactions), examples of corrosion appearances (especially corrosion of adhesive joints), considerations for the design of adhesive joints to avoid corrosion;

— develop protective measures and to put them into practice.

A.3.1.5 Adhesive bonding process

Detailed comprehensive competences, knowledge application, practical application and experiences, with respect to these subject contents (see 5.4.2.2), includes being able to:

— describe comprehensively the various joining techniques;

— explain the advantages of adhesive bonding technology compared to other joining techniques such as welding and riveting;

— explain the disadvantages of adhesive bonding and the limitations regarding the use of adhesively bonded components;

— integrate adhesive bonding into the production planning and to put the planned production into practice.

A.3.1.6 Testing and analysis

A.3.1.6.1 Non-destructive testing

Detailed comprehensive competences, knowledge application, practical application and experiences according to 5.4.2.2, with respect to these subject contents, includes being able to:

— describe and explain the functional principles, the measuring principle and the interpretation of results of the following methods and which failures are detectable with their help: visual inspection, leak test, acoustic emission, tap test, Woodpecker, ultrasound testing (conventional method), X-ray radiography, shearography, Infrared-Thermography, IR spectroscopy, Raman spectroscopy;

— compare the methods with each other considering their capabilities and limitations and the purposes they can be used in the context of adhesive bonding technology;

— describe the rheological phenomena for adhesives (Newtonian behaviour, shear-thinning behaviour, shear-thickening behaviour, thixotropy, rheopexy, flow limit, plasticity, causes (mechanisms, responsible structures, etc.) for deviations from Newtonian flow behaviour (effect of the following parameters on rheological phenomena: physical-chemical state, temperature, pressure, time, rate of shear, methods to measure the viscosity of fluids;

— describe the analytical principle, interpretation of the results and potential applications in adhesive bonding technology of differential scanning calorimetry (DSC)[9], thermal gravimetric analysis (TGA), thermal mechanical analysis (TMA), dynamic mechanical analysis (DMA);

— decide responsibly about the benefits of each method for possible application cases;

— decide responsibly which method to use;

— decide responsibly based on these results necessary measures for the practice.

A.3.1.6.2 Testing of surfaces

Detailed comprehensive competences, knowledge application, practical application and experiences according to 5.4.2.2 with respect to these subject contents, includes being able to:

— assess the surface wettability [water drop test, test inks, contact angle measurement, water break test (WBT), aerosol wetting test (AWT)];

— assess the surface structure [(tactile methods, scattered light technology, scanning electron microscopy (SEM), scanning probe microscopy (SPM)];

— assess the surface composition [IR spectroscopy, X-ray photoelectron spectroscopy (XPS), Auger electron spectroscopy (AES), time-of-flight secondary ion mass spectrometry (ToF-SIMS), energy dispersive X-Ray analysis (EDX), optically stimulated electron emission (OSEE)];

— name the methods that are suitable to be integrated in an adhesive bonding process for quality assurance. (aerosol wetting test, scattered light technology, OSEE);

— explain the measuring principle and interpretation of results for each method (know about the effects on the surface and to describe the physical principles the method is based on);

— compare the methods with each other considering their capabilities and limitations and the purposes they can be used in the context of adhesive bonding technology;

— decide responsibly based on these results necessary measures for the practice.

A.3.1.6.3 Destructive testing

Detailed comprehensive competences, knowledge application, practical application and experiences according to 5.4.2.2, with respect to these subject contents, includes being able to:

— describe the sample geometry, the direction of forces acting while testing, the basic principles of the test procedure and the evaluation of test results (lap shear test, floating roller peel test[2], bead peel test[46]);

— give examples and describe the sample geometry and the direction of the applied load also for other methods based on shear or peel loads;

— explain and interpret destructive test methods (quasi-static, static, etc.), fracture pattern evaluation and interpretation, parameters that influence the test results, stress distribution in adhesively bonded joints;

— decide responsibly based on these results necessary measures for the practice.

A.3.1.7 Quality management

Detailed comprehensive competences, knowledge application, practical application and experiences according to 5.4.2.2, with respect to these subject contents, includes being able to:

— prepare and explain work instructions and to inspect their realization in the practice;

— realize the complete quality management including all QA-measures mentioned above in the practice;

— describe and to explain the following objectives of quality assurance in adhesive bonding technology, special processes (definition and consequences). QA measures for:

  — the planning and development phase;

  — the production phase;

- purchasing of adherends, chemicals, consumables and tools;
- incoming goods inspection;
- storage and in-company transport of adherends, chemicals and consumables;
- ensuring an adequate work place for adhesive bonding processes;
- surface treatment of adherends;
- preparation of adhesives;
- dosing and application of adhesives;
- disposal of chemicals;
- handling of non-conforming products;
- joining and fixing;
- different curing/hardening processes;
- storage, in-company transport and dispatch of adhesively bonded parts;
- production, testing and evaluation of routine test samples;
- the period of use (inspection, maintenance, repair);
- higher level supra-processes.

A.3.1.8 Manufacturing and production processes

Detailed comprehensive competences, knowledge application, practical application and experiences according to 5.4.2.2, with respect to these subject contents, includes being able to:

- describe and explain things to consider during the manual application of adhesives: preparing a workplace suitable for adhesive bonding, preparing chemicals (adhesives, adhesion promotors, etc.) and adherends, processing of the adhesive; selection of suitable tools; selection and location of balances for dosing of adhesive components, adhesive application, joining and fixing, curing and hardening; hardening at elevated temperatures, beads, spot application, spray application, roller application, pouring methods, printing methods, dosing, using balances, 2-C proportioner, twin cartridges with application guns, pressure-time dosing, methods and limitations for monitoring the volume flow for automatic dosing, components of application systems (operating principles, features, advantages and disadvantages), material feed/supply systems, pumps: gear pumps, membrane pumps, piston pumps (single- and double-action), eccentric screw pumps, hose pumps, valves: Needle valves, snuff-back valves, pinch valves, mixers: static mixers, dynamic mixers, counter current injection mixers, hoses: PA or PTFE core;
- develop outline concepts for dosing equipment;
- develop a statistical process control: potential and limitations of machine capability studies for adhesive dosing equipment;
- develop and implement plant protection and component safety/reliability and protective measures for personnel;
- describe things to consider during the automatic application of adhesives: robots in adhesive bonding technology, automation (criteria, consequences), definition: industrial robot, selection criteria for industrial robots, SCARA and articulated robots, components of a robot system, protective measures and safety devices concerning robots and robot areas, comparison of operation modes: moving workpiece/moving application unit, influences on the application pattern/application quality,

recognition of application errors; solution of the problem, available programming techniques (online/offline), interpolation methods (PTP/LIN/CIRC);

— develop outline concepts for automatic production;

— develop a statistical process control: potential and limitations of machine capability studies for automatic production;

— develop and implement plant protection and component safety/reliability and protective measures for personnel in automatic production;

— describe in connection with adhesive bonding on painted surfaces typical layer-build-up of painted surfaces, things to consider when adhesive bonding on painted surfaces, additives influencing adhesion on painted surfaces, cross-cut test;

— describe risk assessment, obligations of employers and employees, hazardous substances: labelling and packaging on bringing materials into use; in-company labelling, Globally Harmonised System of Classification and Labelling of Chemicals (GHS), pictograms and their meaning, hazard statements an precautionary statements, signal words, product identifiers, exposure limits for workplaces (OEL, DNEL, BLV), uptake pathways of hazardous substances into the human body;

— describe the use, purpose and content of safety data sheets, personal protective equipment, protective measures, waste disposal;

— develop and implement adhesive bonding processes also for painted surfaces;

— put responsibly adhesive bonding processes into practice.

A.3.1.9 Maintenance

Detailed comprehensive competences, knowledge application, practical application and experiences according to 5.4.2.2 with respect to these subject contents, includes being able to:

— transfer in a correct manner and with responsibility the issues mentioned in A.3.1.1 to A.3.1.8 to the certain specific maintenance/repair case.

A.3.2 Specific — Detailed definitions

A.3.2.1 Adhesion and adhesives

Detailed specific competences, knowledge application, practical application and experiences according to 5.4.2.3, with respect to these subject contents, includes being able to:

— describe what an adhesive is and explain the principle of how an adhesive works;

— briefly explain what a chemical bond is;

— explain the meaning of permanent dipole and induced dipole;

— explain the difference between non-polar, polarizable, and polar substances;

— describe how physical interactions arise and how their properties differ from those of chemical bonds;

— describe what adhesion and cohesion are and explain what forces are involved;

— explain what is meant by wetting;

— determine when there is good wetting and when there is poor wetting;

— explain test methods for measuring wetting;

— name the conditions for effective wetting;

— explain the relationship between wetting and adhesion;

— describe what a polymer is and be familiar with the different types of polymers and their structures;

— name the different classes of plastics and describe their structures and typical properties;

— describe the classification of adhesives based on their chemical structure;

— describe the classification of adhesives based on their setting mechanism and assign adhesives into these classes;

— describe and explain the fundamental differences between physically hardening adhesives, chemically curing adhesives, and adhesives which do not solidify;

— name the different curing reactions (polyaddition, polycondensation, polymerization) of chemically curing adhesives and to be able to explain the principles of these reactions and any special features;

— name the different hardening mechanisms of physically hardening adhesives and to be able to explain the special features of these mechanisms;

— name adhesives which do not harden and explain how they function;

— be familiar with the advantages and disadvantages of adhesives that cure via a combination of solidification mechanisms and to be able to give examples of such adhesives;

— assign the different adhesives discussed in the theory to a solidification mechanism;

— explain the different processing variants, processing times, and processing conditions of adhesives;

— qualitatively describe the properties of the cured/hardened adhesives;

— develop, implement and inspect necessary measures in the certain area of responsibility concerning the long term-stable adhesion and the correct application of the adhesives and to know when this area of responsibility will be overstepped.

A.3.2.2 Materials as adherends

Detailed specific competences, knowledge application, practical application and experiences according to 5.4.2.3, with respect to these subject contents, includes being able to:

— describe the fundamental structure of metals and their adhesive bonding-related properties;

— describe the adhesive bonding-related properties of low-alloy, high-alloy, and galvanized steel and also aluminium;

— describe the fundamental structure of plastics and their adhesive bonding-related properties;

— explain the adhesive bonding properties of different plastics using terms such as polarity, reactivity, chain mobility, and additives;

— describe the fundamental structure of float glass and its adhesive bonding-related properties;

— explain why a gel layer forms on float glass and the relevance of this for adhesive bonding;

— describe the fundamental structure of fibre reinforced plastics (fibres, matrix systems, laminate structure, peel-ply) and their adhesive bonding-related properties;

— explain the requirements of adherend surfaces for effective adhesive bonding and the objectives of surface treatment;

— explain the different layers of a cross-section of a metal and plastic;

— explain, in relation to surface preparation, the meaning of acclimatization, visible inspection, and checking the accuracy of fit;

— explain different cleaning processes for surface pre-treatment (metal and plastic surfaces) and the requirements on cleaning agents;

— explain why silicones shall be absolutely avoided for efficient adhesive bonding;

— name possible sources of silicones;

— explain different surface pretreatment methods including sanding/grinding, grit blasting, pickling, anodization, SACO, flame pyrolysis, flame treatment, and plasma treatment;

— explain the function of a adhesion promotor for surface post-treatment;

— demonstrate in a practical way how to use a adhesion promotor;

— inspect the correct execution of the work instructions and to notice deviations;

— know which actions in each case are necessary [own actions, message to the Adhesive Bonding Coordinator (ABC)] and in which way these actions have to be carried out.

A.3.2.3 Construction and design

Detailed specific competences, knowledge application, practical application and experiences according to 5.4.2.3 with respect to these subject contents includes being able to:

— explain the deformation behaviour of materials on undergoing temperature changes;

— explain and assess the possible consequences of adhesive bonding together materials that undergo different deformation on temperature change;

— explain the deformation behaviour of materials subjected to tensile and shear stress;

— explain the meaning of stress, strain, modulus of elasticity, shear strain, shear modulus, and Hooke's law;

— draw and interpret stress-strain curves;

— explain the deformation behaviour of polymers on being subjected to mechanical stress;

— explain the meaning of elastic, plastic, and viscoelastic deformation;

— name and explain factors which influence the mechanical properties of polymers;

— explain the meaning of glass transition temperature;

— explain the meaning of tensile stress, shear stress, and peel stress and their relevance for adhesive bonding;

— describe the stress distribution in an adhesively bonded joint with ideally stiff adherends;

— describe the stress distribution in an adhesively bonded joint with real adherends;

— name and explain factors which influence the strength of adhesively bonded joints;

— describe the procedure for selecting an adhesive;

— name the content of a summary of requirements and give examples;

— describe what is meant by stress/load and stress/load limit;

— name and explain the advantages of hybrid methods over solely mechanical joining methods and over solely adhesive bonding;

— name and explain the joining techniques of clinching, punch riveting (solid rivets and semi-hollow rivets), blind riveting, folding, and resistance spot welding;

— name any special features when combining adhesive bonding with one of the aforementioned joining techniques;

— name and explain the various process variants for hybrid joining: the fixing method, the injection method, and the sequential method.

A.3.2.4 Durability

Detailed specific competences, knowledge application, practical application and experiences according to 5.4.2.3, with respect to these subject contents, includes being able to:

— name the causes of ageing of adhesively bonded joints;

— explain the effects of moisture, mechanical forces, radiation, and temperature changes on adhesively bonded joints;

— name and briefly describe different ageing tests;

— inspect protective measures and to notice deviations due to inadequate protective measures that need to be counteracted.

A.3.2.5 Adhesive bonding process

Detailed specific competences, knowledge application, practical application and experiences according to 5.4.2.3, with respect to these subject contents, includes being able to:

— name and briefly describe the various joining techniques;

— name and explain the advantages of adhesive bonding technology compared to other joining techniques such as welding and riveting;

— name and explain the disadvantages of adhesive bonding and the limitations regarding the use of adhesively bonded components;

— inspect the application of adhesive bonding in the production;

— identify irregularities;

— implement remedial measures in their area of responsibility, if necessary.

A.3.2.6 Testing and analysis

Detailed specific competences, knowledge application, practical application and experiences according to 5.4.2.3, with respect to these subject contents, includes being able to:

— explain the principle of non-destructive test methods;

— describe what defects can be detected in adhesively bonded joints using non-destructive methods;

— explain what information can be obtained from visual joint inspection, ultrasound testing, and thermography;

— explain the principle of destructive test methods;

— explain why adhesively bonded joints shall be tested using destructive tests;

— name and describe the different fracture patterns;

— assess what fracture pattern is desirable, and give possible reasons for other fracture patterns;

— describe the lap shear test procedure and required specimen form and to be able to explain how the joint strength is calculated;

— explain the procedure for the bead peel test[46];

— describe the floating roller peel test[2] procedure and required specimen form and to be able to explain how the peel resistance is calculated;

— name and describe the content of a test record;

— interpret test results for necessary measures.

A.3.2.7 Quality management

Detailed specific competences, knowledge application, practical application and experiences according to 5.4.2.3, with respect to these subject contents includes, being able to:

— describe how to design a workplace approved for adhesive bonding work;

— explain what preparatory work is required before adhesive bonding processes are carried out;

— describe and assess the content of work instructions;

— explain what is meant by the phrase “adhesive bonding is a special process”;

— name quality assurance measures for production and give examples;

— inspect quality assurance measures for production and to identify irregularities.

A.3.2.8 Manufacturing and production processes

Detailed specific competences, knowledge application, practical application and experiences according to 5.4.2.3 with respect to these subject contents includes being able to:

— explain the processing of adhesives manually, using machines, and using automated technology and what shall be taken into account for each combination;

— explain the configuration of a dosing unit for 2-C adhesives;

— name the different components of a dosing unit and briefly explain their functions;

— explain the difference between moving-component systems and moving applicator robot systems;

— name possible application errors when processing adhesives using robots;

— assess what measures to take if there are abnormalities in the adhesive bonding process;

— explain how one recognizes a hazardous substance and how hazardous substances is to be labelled;

— understand the different hazard pictograms and their meanings;

— name sources of information about hazardous substances;

— name the uptake routes for hazardous substances into the human body;

— be familiar with and be able to briefly explain the sequence of priority of protective measures;

— determine what personal protection equipment is required when working with hazardous substances in adhesive bonding processes and to be able to use this equipment;

— briefly explain what is meant by workplace limit value (WLV) and biological limit value (BLV);

— explain what is to be heeded when disposing of waste materials arising from adhesive bonding processes;

— be able to assess how the waste is to be disposed;

— inspect adhesive bonding processes in the practice, to identify irregularities and to implement remedial measures in their area of responsibility, if necessary.

A.3.2.9 Maintenance

Detailed specific competences, knowledge application, practical application and experiences according to 5.4.2.3 with respect to these subject contents includes being able to:

— transfer in a correct manner, but without overstepping the area of competences the issues mentioned in A.3.2.1 to A.3.2.8 to the certain specific maintenance/repair case.

A.3.3 Basic: Detailed definitions

A.3.3.1 Adhesion and adhesives

Detailed basic competences, knowledge application, practical application and experiences according to 5.4.2.4 with respect to these subject contents includes being able to:

— describe the differences between physical and chemical processes;

— describe when physical interactions occur and how they differ from chemical bonds;

— explain what an adhesive is and the fundamental mechanisms of adhesives;

— describe the terms adhesion and cohesion and explain what types of forces are responsible for adhesion and cohesion;

— explain what wetting means and assess whether one has effective or ineffective wetting;

— name the conditions for effective wetting;

— explain test methods for measuring wetting, including the water droplet method;

— explain the relationship between wetting and adhesion;

— describe what a polymer is and be familiar with the different types of polymer structures;

— name the different classes of plastics, their structures, and typical properties;

— describe the classification of adhesives based on their solidification mechanism;

— assign the adhesives into these classes;

— describe and explain the fundamental differences between physically hardening adhesives, chemically curing adhesives, and adhesives which do not solidify;

— name the different curing reactions (polyaddition, polycondensation, polymerization) of chemically curing adhesives;

— name the different hardening mechanisms of physically hardening adhesives and to be able to explain the special features of these mechanisms for the practice;

— name the work steps which are to be completed within the certain processing times and assess what factors affect the pot life and skinning time;

— assign the different adhesives to a solidification mechanism;

— qualitatively describe the properties of the cured/hardened adhesives;

— apply an adhesive in a correct manner according to the given work instructions.

A.3.3.2 Materials as adherends

Detailed basic competences, knowledge application, practical application and experiences according to 5.4.2.4, with respect to these subject contents, includes being able to:

— name the requirements on adherend surfaces (metals, plastics, FRPs, etc.) for effective adhesive bonding and the objectives of surface treatment (cleaning, grinding, gritblasting, etching, flame or plasma treatment, primer, etc.) prior to adhesive bonding;

— name the objective of cleaning adherend surfaces prior to adhesive bonding and the requirements on cleaning agents;

— name why silicones are to be totally avoided when carrying out adhesive bonding work and to name potential sources of silicones;

— carry out surface treatments (metals, plastics, FRPs, etc.) in a correct manner according to the given work instructions.

A.3.3.3 Construction and design

Detailed basic competences, knowledge application, practical application and experiences according to 5.4.2.4, with respect to these subject contents, includes being able to:

— name and explain the different mechanical loads to which adhesively bonded joints are subjected;

— DE-241 assess what loads are most favourable for adhesively bonded joints.

A.3.3.4 Durability

Detailed basic competences, knowledge application, practical application and experiences according to 5.4.2.4, with respect to these subject contents, includes being able to:

— name the causes of ageing of adhesively bonded joints;

— explain the effects of moisture on adhesively bonded joints.

A.3.3.5 Adhesive bonding process

Detailed basic competences, knowledge application, practical application and experiences according to 5.4.2.4, with respect to these subject contents, includes being able to:

— name and briefly explain the advantages of adhesive bonding technology compared to other joining techniques such as welding and the use of screws/bolts;

— name and explain the different processing variants and processing conditions of adhesives;

— name and briefly explain the disadvantages of adhesive bonding and limitations regarding the use of adhesively bonded components;

— carry out the adhesive bonding process a correct manner according to the given work instructions;

— give a feedback if irregularities seem to occur.

A.3.3.6 Testing and analysis

Detailed basic competences, knowledge application, practical application and experiences according to 5.4.2.4, with respect to these subject contents, includes being able to:

— explain why adhesively bonded joints have to be tested using destructive tests;

— name and describe the different fracture patterns, assess what fracture pattern is desirable, and give possible reasons for other fracture patterns;

— name the methods for testing adhesively bonded joints;

— describe the lap shear test procedure and required specimen form and to be able to explain how the joint strength is calculated;

— explain the procedure for the bead peel test[46];

— describe the floating roller peel test[2] and required specimen form;

— name the parameter measured in the floating roller peel test[2];

— name and briefly describe the different ageing tests;

— carry out adhesive bonding tests a correct manner according to the given work instructions.

A.3.3.7 Quality management

Detailed basic competences, knowledge application, practical application and experiences according to 5.4.2.4, with respect to these subject contents, includes being able to:

— describe how a workplace is to be designed for adhesive bonding work;

— explain what preparatory work is required before adhesive bonding processes are carried out;

— understand the content of work instructions;

— briefly explain what is meant by the phrase “adhesive bonding is a special process”;

— name quality assurance measures for production and give examples;

— give a feedback if irregularities seem to occur.

A.3.3.8 Manufacturing and production processes

Detailed basic competences, knowledge application, practical application and experiences according to 5.4.2.4, with respect to these subject contents, includes being able to:

— explain the special features of curing reactions (polyaddition, polycondensation, polymerization) for the practical work;

— explain the terms pot life and skinning time;

— name examples of adhesively bonded products;

— explain how one recognizes a hazardous substance and how hazardous substances are to be labelled;

— understand the various hazard symbols and their meanings;

— name sources of information about hazardous substances;

— name the uptake routes for hazardous substances into the human body;

— determine what personal protection equipment is required when working with hazardous substances in adhesive bonding processes;

— explain what is to be heeded regarding the disposal of waste materials arising from adhesive bonding processes;

— assess how the waste is to be disposed;

— carry out adhesive bonding processes a correct manner according to the given work instructions and to refer a feedback to the right place in the company if irregularities seem to occur.

A.3.3.9 Maintenance

Detailed basic competences, knowledge application, practical application and experiences according to 5.4.2.4 with respect to these subject contents includes being able to:

— transfer in a correct manner, but without overstepping its competences the issues mentioned in A.3.3.1 to A.3.3.8 to the certain specific maintenance/repair case;

— be aware in which certain cases which responsible person should be informed/asked;

— carry out maintenance and repair processes in adhesive bonding in a correct manner according to the given work instructions and to refer a feedback to the right place in the company if irregularities seem to occur.

Annex B
(informative)

Requirements

Table B.1 summarises the major items to be aware of regarding the requirements to be considered and provides support in this context, also so that possible requirement aspects are not left out of the listing.

Table B.1 — Major items dealt with in a list of requirements

	Subject	Examples
1	Geometry	Dimensions of adhesively bonded joints and adjacent components, tolerances for adherends
2	Kinematics and forces/loads	Velocity, acceleration and frequencies, aerodynamic loads (e.g. passage through tunnels, on-coming trains, cross winds), static loads (e.g. imposed loads, self-weight, accidental loads), collision and impact Loads are to be considered in terms of direction, magnitude and frequency. Quasi-static (directional load cases) Shock/Impact Crash
3	Materials	Physical and chemical properties of adherends and adhesives, auxiliary materials, materials with specified characteristics, characteristic values (e.g. coefficient of linear thermal expansion, electrical conductivity of adhesive, damping), surface condition
4	Safety	Operational reliability of production and vehicles (e. g. strength, fire protection), occupational health and environmental protection (e.g. volatile organic compounds, reaction by-products, toxicology), Classification of adhesively bonded joints as in Clause 4
5	Ergonomics	Human-machine interaction: handling, mode of control, clear displays, illumination, design
6	Manufacture and assembly	Limitations arising from production site (e.g. dust, aerosols, humidity, temperature, storage conditions), maximum dimension to be manufactured, preferred manufacturing technique, tools, achievable quality and tolerances, restrictions due to material characteristics (e.g. pot life, skin formation time, curing time, effects of temperature and volume change by reaction during adhesive bonding process). Any specifications for assembly (e.g. sequence, movement during assembly), details of assembly, installation, on-site assembly
7	Proof of conformity	Calculations, component testing, finite element analysis, analyses and certificates; qualification testing of adherend materials, adhesive, surfaces and components; facilities for measurement and testing, any special regulations, standards, codes of practice and instruction material
8	Shipping and storage	Shipping method and conditions, handling during transport, logistics from supplier to customer including storage conditions
9	Use	Application and sales area, site of use (e.g. climate, environment), ageing (e.g. due to UV radiation, moisture), exposure to chemicals (e.g. cleaning agents), operating temperature, differential temperature, sound insulation
10	Maintenance	Ease of repair, freedom from maintenance or maintenance intervals and time required for servicing, inspections, exchange of components and repair, any paint coating, cleaning
11	Recycling	Reuse, recovery, dismantling, separation of materials, disposal
12	Costs	Production costs, tooling costs, investment costs, amortization costs, lifecycle costs (LCC)
13	Scheduling	End of design stage, delivery times (e.g. for material, equipment, proof of conformity documents)
14	Fire and smoke	Requirements for fire behaviour of materials and components, see ISO 8421-2

Annex C
(informative)

Guideline for the implementation of the design of adhesively bonded joints and its verification

C.1 Design and verification of adhesively bonded joints — General

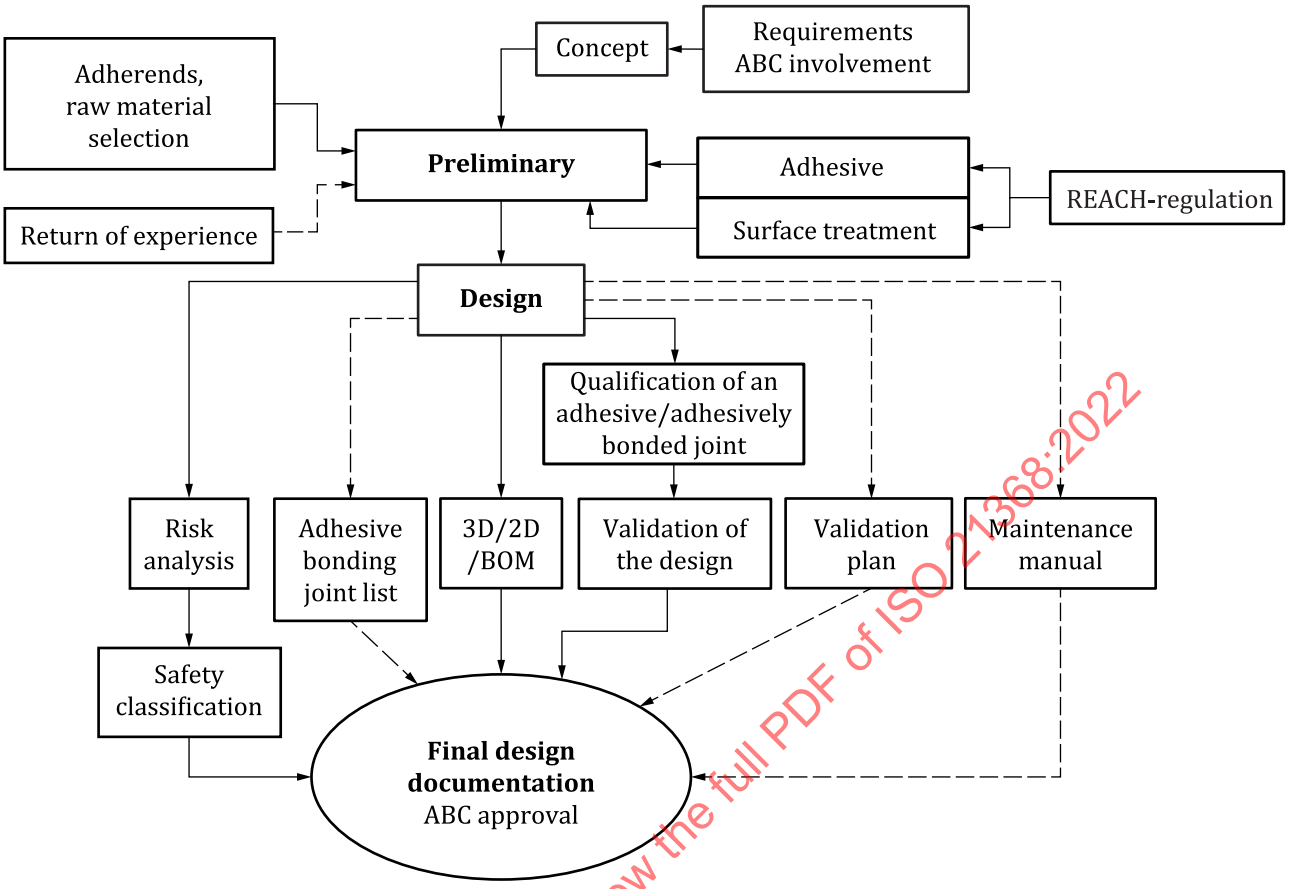
This annex describes the procedure in the case of design, dimensioning and proof of verification management including damage tolerance for adhesive bonding of metallic and non-metallic materials in the production as well as in the maintenance. The aim is to design, to dimension and to verify the proper execution of adhesively bonded joints, taking into account all geometric, material, loads and environmental influences (e.g. cleaning agents, UV radiation, temperature, humidity, etc.).

Developments in regard of calculation methods and adhesives as well as innovative developments by the user-companies, carriers and adhesive suppliers should not be derogated.

C.2 Design process

C.2.1 Flow chart

Figure C.1 is an example and not a strictly chronological guideline.



NOTE Dotted line: optional documents to be defined in a specification of a technical nature to be agreed between the order giving and order taking partners.

Figure C.1 — Principle of flow chart

C.2.2 Requirements

Every adhesively bonded joint shall fulfil specific requirements.

Requirements for the adhesively bonded joints are to be defined in the design phase. These are derived from the project specifications (legal, contractual and internal requirements) and are to be documented. 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 can be derived from the requirements.

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 Examples of mechanical loads can be extracted from the general standards. See Table B.1.

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

The requirements can be established using the main parameters as shown in Table B.1.

C.2.3 Preliminary design and general design parameters

C.2.3.1 Design principles

The design solution is influenced by the loads or effects from the requirement list.

C.2.3.2 Adherends raw material selection

Adherends shall be chosen accordingly to the list of requirements (properties shall be known because the adhesion can be affected). Raw material shall be taken into account for the surface treatment or the surface properties (e.g. screen printing, roughness, etc.). The effects of corrosion or the long-term stability of the adherends shall be identified. Chemical composition of raw material can affect the adhesive itself or the adhesion.

C.2.3.3 Return on experience

Experience of older solutions is to be considered for the design of adhesively bonded joints.

C.2.3.4 Adhesive selection

Adhesives are chosen accordingly to the requirements (e.g. low modulus adhesive or high modulus adhesive, solidification process, etc. (see Annex D). All available information (data sheets from adhesive suppliers, internal data, return on experience, laboratory advice) are used for the selection.

Adhesive selection can be refined throughout the whole design process. When selecting the adhesive system, make sure that the properties of the adhesive are not considered in isolation, but as part of the entirety of the adhesively bonded joint. A major aspect of adhesive bonding is the adhesion of the adhesive on the surface. In addition, manufacturing conditions as described in Clause 8 shall be taken into account (relevant design and manufacturing documentation).

The choice of the adhesive bonding system can be made based on Annex D.

C.3 Design

C.3.1 General

The strength of an adhesively bonded joint is closely related to several factors. These include the:

— physical and mechanical properties of the individual parts of the joint itself;

— geometry of the joint;

— extent and level of the adhesive and cohesive interactions within the adhesively bonded joint.

All these factors shall be determined in the design phase of the adhesively bonded structure.

C.3.2 Risk analysis and safety classification

The classification of each individual adhesively bonded joint produced by adhesives is exclusively based on the potential damage that may arise by the failure of the joint itself, independent from the cause of failure. Particularly, the consequences of the failure of an adhesively bonded joint are evaluated based on safety aspects (risk of fatalities or injury of people/environmental damages) and functional aspects of the system. The occurrence and the resulting consequences of failures are independent from the strength and the deformation behaviour as well as from the solidification mechanism of the used adhesive.

The classification into a safety class specified in Clause 4 applies to each adhesively bonded joint.

C.3.3 Adhesively bonding joint list

The adhesive bonding joint list is an overview of all adhesively bonded joints of a project or sub-system. If an adhesively bonding joint list is required, the following minimum information shall be listed in such document:

— system designation (project name);

— adhesively bonded joint number or name;

— assembly/sub-assembly number (drawing number, bill of material);

— safety class.

C.3.4 Qualification of an adhesive

C.3.4.1 General

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

In both cases, the main function of the adhesive is to join the adherends. If the adhesive is also designed to accommodate deformations and compensate for major deviations in component dimensions, then nonlinear elastic, low-modulus adhesives are normally used. Where the transfer of high loads is involved, then high-modulus adhesives are usually used.

C.3.4.2 Physical properties of adhesives

The physical properties are 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. The test specimens for determining the load limit of adhesively bonded joints are manufactured according to the processes, adhesives and surfaces to be used in service. If cohesive failure of the joint occurs, the failure will be due to the adhesive as such.

If not specified otherwise, the cohesive failure ratio for aged or unaged specimens is given at least as defined in Table C.1. 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.

Where not otherwise specified, the cohesive failure ratio for aged or non-aged test specimen shall be at least as defined in Table C.1.

For positive results of adhesion tests, the failure patterns according to ISO 10365 are accepted:

— cohesive failure (CF);

— special cohesive failure (SCF);

— failure with stress whitening of the adhesive (SWCF);

— substrate failure (SF).

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

Table C.1 — Failure criteria in adhesively bonded joints (given for adhesively bonded joints to be calculated Class S1 or S2)

Adhesive classification	Failure pattern	Comment
Low-modulus adhesive with layer thickness ≥1,5 mm	S1/S2: ≥95 % CF + SCF + SF S3: ≥75 % CF + SCF + SF	For all the tested adhesive bonding areas
High-modulus adhesives	S1/S2/S3: ≥70 % CF + SCF + SF	For all the tested adhesive bonding areas

This classification in Table C.1 will be defined on a product-by-product basis by each individual technical product committee or product group.

If high-modulus adhesives are applied on coatings (e.g. adhesion promotors or varnishes), failure of the adhesively bonded joint shall be cohesive in the coating or in the adhesive. In such cases, the cohesion of the coating, the adhesive or the adherent determines the stress limit of the adhesively bonded joint. In such cases, the analysis is to be carried out for the adhesively bonded joint together with the coating.

Adhesively bonded joints with fibre-reinforced composite adherends are designed to ensure that failure is cohesive, i.e. occurs in the adhesive or the adherend. In case the determination and/or assessment of the failure pattern is difficult or unclear, additional competence shall be involved under responsibility of the ABC. 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.

Which methods for accelerated ageing (see Annex F) are to be selected and used as suitable depends in each case on the requirements defined and specified in the planning phase (see Annex B) for the adhesively bonded joint or the adhesively bonded product.

C.3.4.3 Adhesion

The results of the following are only for the characterisation of the adhesives (low modulus adhesives and high modulus adhesives). These results are not valid for production samples.

The interpretation of the results of the work samples produced in the production is the responsibility of the ABC.

— Low modulus adhesive:

  Depending on the respective requirements, low-modulus elastomeric adhesives can be subjected to the bead peel test according to ISO 21194. ISO 21194 specifies a method for evaluating the adhesion of elastic adhesive bonding and sealing materials with a minimum elongation at break of 100 % and a modulus of elasticity of maximum 10 MPa[43] on different substrates. In this way, the effect of different coatings, surface treatments of substrate materials, ageing behaviour, etc. on adhesion can be compared and thus the influence of surface treatment, substrate and adhesive on the long-term stability of adhesive and sealant bonds can also be evaluated.

  Results of the bead peel test itself do not provide strength values that can be used, for example, for the design of the adhesively bonded joint. Such adhesive bond values are obtained by other tests (see Annex E).

— High modulus adhesive

  For high-modulus adhesives, proof of adequate adhesion is to be taken into account during mechanical test (e.g. lap shear, tensile test, pull-off test, etc.). The analysis and definition of the failure pattern is based on ISO 10365.

C.3.4.4 Permissible stress and strain

Permissible stress or strain values are obtained by testing adhesively bonded joints. In the analysis, it is necessary to determine characteristic values as determined as in C.5 for class S1 adhesively bonded joints, with a confidence interval of $1 - \alpha = 95$ %. The same applies to the probability of at least 95 %. For class S2 adhesively bonded joints it is also necessary to determine characteristic values with a confidence interval of $1 - \alpha = 95$ % and to base the prediction rate (probability) on at least 90 %.

The permissible stress or strain is expressed as the characteristic value for the possible stress limit under the relevant operating conditions.

Permissible stress or strain can be described using suitable equivalent stress/strain considerations. For the sake of consistency, when analysing local stress and stress resistance, the same considerations are to be made.

The permissible stress or strain can also be derived from available equivalent results or experience gained in practice.

C.3.4.5 Quasi-static adhesive bond strength

The adhesives are tested in accordance with this annex. Special assemblies such as adhesively bonded sandwich panels, adhesively bonded honeycomb sandwich panels and foamed materials is performed in accordance with the relevant technical rules. In all cases, the characteristic value (see C.5.2) shall be given and the failure pattern shall be described (see ISO 10365). If the operating conditions and the safety class so require, the adhesive bond strength needs to be determined as a function of the temperature or following exposure to chemical agents.

C.3.4.6 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 are 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 where the creep limit of the adhesively bonded joint is low. The permissible creep strain at a given point in time (to be specified by the 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 C.5.3.6.

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). The permissible elongation is below the maximum strain at which 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 C.5.3.5.

Case b) is normally relevant only where low-modulus, elastomeric adhesives are used. The elongation at break after is markedly lower than that measured 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.

C.3.4.7 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, giving due consideration to the influence of the mean stress (susceptibility to creep). Information on the measurement of fatigue strength is given in C.5.3.7 and C.5.4.4.

C.3.4.8 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 are to be determined at the relevant strain rates.

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

C.3.4.9 3D/2D/Bill of material (BOM)

For every assembly the 3D-models or 2D-drawings in combination with the bill of materials are the leading documents for any following process. 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 are:

— adherend material;

— adherend surfaces;

— adhesive;

— surface treatment;

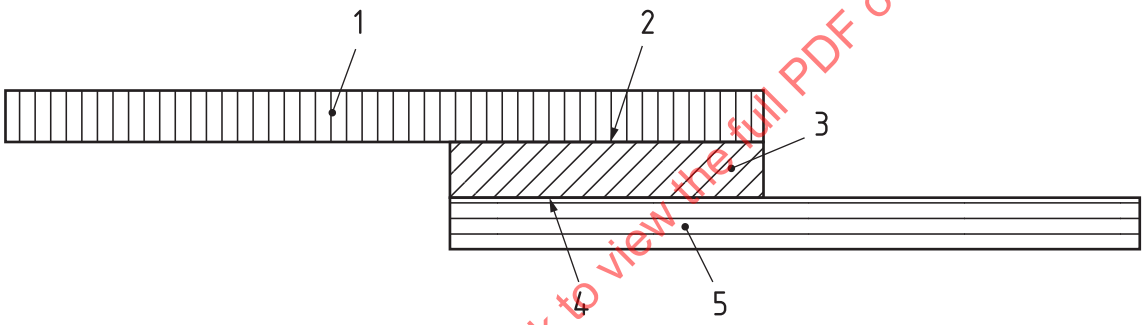
— delay between surface treatment and adhesive bonding;

— dimensions and positions including tolerances;

— safety class;

— reference to this document.

Figure C.2 gives an example how this information could be implemented into drawings. It is essential that a precise link between surface pre-treatment and adherend surface be 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

Figure C.2 — Example 2D drawing for adhesively bonded joints

Adhesive bonding symbols can be used to simplify the drawings (see C.7).

C.4 Validation of the design

C.4.1 General

The scope of the validation depends on the class assigned to the adhesive bond (see Table C.1). The validation of the design (see Figure C.3) can be made using one of the following methods:

1) calculation of each adhesively bonded joint and then compared with the admissible value;

2) components (e.g. sections of these) are tested under realistic conditions to determine the strength of parts of the assembly;

3) proven design by documented return on experience;

4) methods 1, 2 and 3 can be combined.

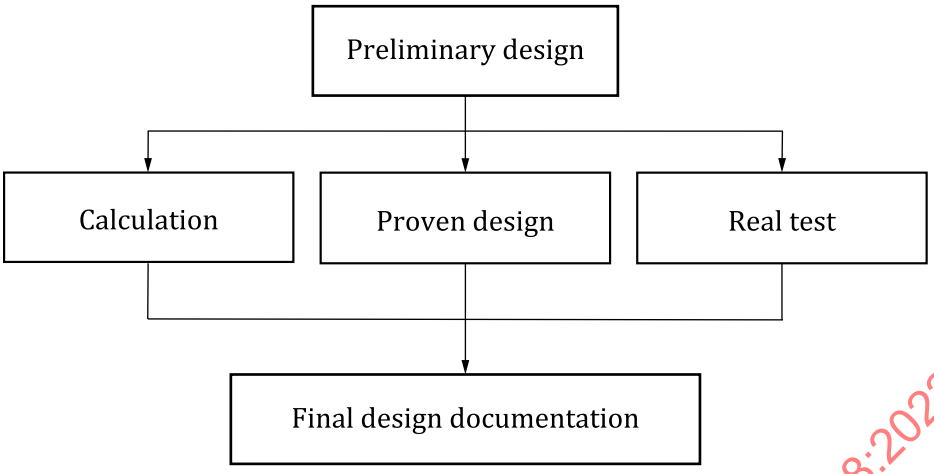


Figure C.3 — Proof of validation — Flow chart

C.4.2 Identifying of the influences/loads

C.4.2.1 General

Load cases are the influences from the requirements and the stresses are the influences bearing by the adhesively bonded joint.

C.4.2.2 Examples of mechanical loads

Some examples of mechanical loads are listed in Table C.2.

Table C.2 — 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

C.4.2.3 Examples of non-mechanical loads

Some examples of non-mechanical influences are listed in the Table C.3.

Table C.3 — Non-mechanical influences on adhesively bonded joints

	Chemical and microbiological influences	**Thermal and other physical influences**
Example	Moisture (Corrosion) Cleaning agents De-icing salt Bacteria Moulds	Thermal effects Photochemical (UV) Electromagnetic Electric Fire and smoke see also ISO 8421-2

For all these influences mentioned in Table C.3, the following parameters shall be taken into account:

— type (direction);

— intensity;

— duration;

— frequency.

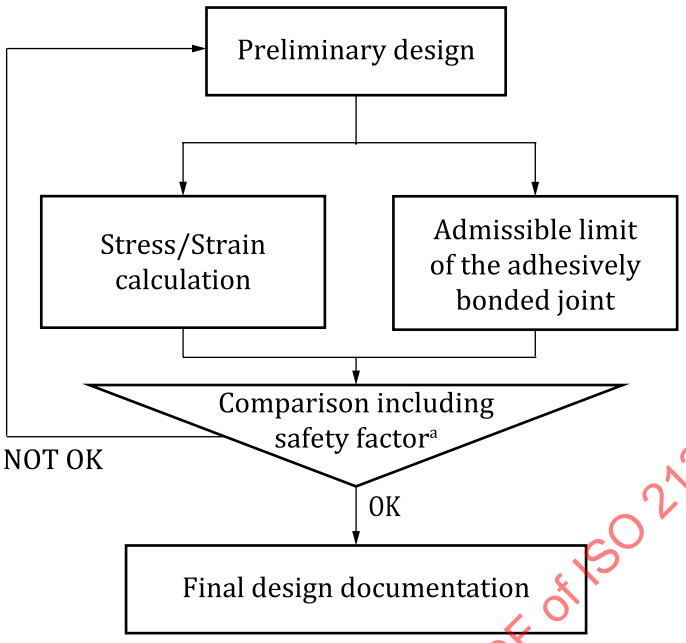
A load case is a combination of previous influences and parameters that influence the adhesively bonded joint at the same time. In general, for one design it is typical to have different load cases.

The relevant load cases need to be integrated in the test plan for validation of the adhesively bonded joint.

C.4.3 Calculation

C.4.3.1 General

Result of the calculation is a comparison (see Figure C.4) between calculated stress and strain occurring on the adhesively bonding joint and the admissible stress and strain of the adhesive.



[a] Safety factors also depend on the knowledge or experience of the company. The knowledge and experience of the company can be incorporated into the determination of safety factors.

Figure C.4 — Calculation process

C.4.3.2 Determining stresses/strains

C.4.3.2.1 General

Structural design is to be performed using an analytical approach or finite element analysis (FEA), depending on the case in question. The design methods used and the results obtained are to 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. Rough estimation of adhesive bonding area can be also suitable in case the safety relevance of the adhesively bonded joint is low and/or adhesive bonding area is extremely oversized.

Stresses are to be derived from the requirements profile. Depending on the elasticity of the adhesive and the particular load case, adhesively bonded joints need to be analysed considering stress (strength) or strain (deformation).

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

C.4.3.2.2 Finite element analysis (FEA)

The finite element analysis (FEA) permits the determination of local stresses or strains 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.

When using spring elements – which are often used in the analysis of nonlinear elastic thick-film adhesively bonded joints - 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 adhesively bonded joint is subjected to tension or compression. Where other equivalent elements are used, the effects of any simplification are to be considered.

For a more rigorous analysis of local stresses, an adequately refined grid is necessary, which is only feasible when sub modelling is used.

The accuracy of the material models and the FE grids used need to 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.

C.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 several mathematic base bodies (e.g. inflexible body, linear elastic body, plate all round fixed, beam in bending).

The nominal approach is a simple analytical concept. The adherend shall be modelled as an inflexible body and the adhesive as a linear elastic body. In this particular case, 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:

— description of the adherend material behaviour: 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.

An unbalanced strain and stress behaviour is the result. Limits of analytic methods are usually:

— adhesively bonded joints with complex geometry;

— irregular stress distribution along the thickness of the adhesive (realisation of hot spots);

— realisation of 3D stress distribution;

— non-elastic material behaviour.

C.4.3.2.4 Admissible stress and strain 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, combination of characteristic values (from the qualification of the adhesive) need to be considered.

C.4.3.2.5 Comparison including safety factor

A comparison of the calculated stresses and strains with the permissible values is required. When determining safety factors, the company's knowledge and experience need to be taken into account in the calculation. These are to be documented.

— Case 1: calculated stress and strain exceed the admissible values; the design shall be improved or reconsidered

— Case 2: calculated stress and strain are below the admissible values; the design of the adhesively bonded joint is verified.

C.4.4 Proven design by documented experience

Proof based on experience requires evidence that the design is adequate. For this reason, an existing design which was used already for another application can be used for a new application and the proven experiences with the already used design can be applied for the new application. To this effect, the demonstration is necessary that both applications are comparable in terms of service conditions (e.g. loads, service time), adherend properties (including surface), adhesive properties and manufacturing processes including surface treatment. The procedure shall be documented in a transparent way.

C.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 similar in terms of their effect on the adhesively bonded joint, proof of which is to be provided. When testing subsystems, consideration of the interaction between them and the overall system is necessary. The same applies to ensuring that the interaction does not inappropriately influence the results. For evaluation purposes, a failure criterion shall be specified. Test results are evaluated statistically. Depending on the knowledge regarding the adhesively bonded joint, how far the test conditions are realistic, and the statistical evaluation applied, a safety factor is integrated into the failure criterion or test conditions. The overall process requires a documentation. This also applies to the decisions taken and their justifications.

C.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 is also be taken to ensure that all parts of the verification process are mutually compatible (e.g. when comparing test results with pass/fail criteria). The procedure needs be documented in a transparent way.

C.5 Determining the stress limit

C.5.1 General

The stress limit for the adhesively bonded joint is determined within the scope of the verification procedure assuming all relevant loading and actions. In the evaluation of results, it is necessary to apply standard statistical procedures, which shall be described transparently in the documentation. Failure scenarios shall be developed when designing tests, which are to be consistent with the tests to be carried out, taking care to ensure that the test conditions are representative of the type and duration of stresses.

Chemical and mechanical stresses should be considered in their combinations as they occur in practice. The stress limit should be determined assuming these combinations.

In the absence of adequate practical knowledge, it may first be established by random testing which stresses or stress combinations are representative of the most unfavourable operating conditions.

Mechanical tests are required to ensure the rates of testing reflect the loading rates encountered in practice. When using parameters originating from different tests, it is to be ensured that the rates of strain are consistent.

C.5.2 Characteristic values and the permissible stress limit

Values for the stress limit are expressed as characteristic values. Characteristic values take the uncertainty of measured values into account and are a prerequisite for permitting a statement

regarding the probability of failure or life of an adhesively bonded joint. Characteristic values (R_c) can be calculated in accordance with ISO 16269-6 using Formula (C.1):

$$R_c = \bar{R} - k_m\,(P, 1-\alpha, n) \times \Delta R \qquad \text{(C.1)}$$

where

R_c is the design value (e.g. strength, yield strength, elongation at break) denoting the stress limit;

$\bar{R}$ is the mean of all measured stresses;

ΔR is the standard deviation;

$k_m\,(P, 1-\alpha, n)$ is a function of the statistical distribution, the type of tolerance interval (one-sided or two-sided);

P is the probability (prediction rate), the confidence level $1-\alpha$, and the number of measured values under consideration n (degrees of freedom) (see ISO 16269-6:2014, Table C.2).

Table C.4 lists some values for coefficient k_m for class S1 and S2 adhesively bonded joints, considering the normally relevant one-sided statistical tolerance interval and assuming a normal distribution of the population:

Table C.4 — One-sided statistical tolerance interval (unknown variance), normal distribution (as in ISO 16269-6)

$1-\alpha$ (for Class S1 and Class S2		
n	P (for S2) = 0,90	P (for S1) = 0,95
2	20 581 5	26 259 7
3	6 155 3	7 656 0
4	4 162 0	5 143 9
5	3 406 7	4 202 7
6	3 006 3	3 707 7
7	2 755 5	3 399 5
8	2 582 0	3 187 3
9	2 453 8	3 031 3
10	2 354 7	2 911 0
11	2 275 4	2 815 0
12	2 210 2	2 736 4
13	2 155 5	2 670 6
14	2 108 8	2 614 5
15	2 068 4	2 566 1
16	2 033 0	2 523 7
17	2 001 8	2 486 3
18	1 973 8	2 453 0
19	1 948 7	2 423 1
20	1 926 0	2 396 1
22	1 886 5	2 349 0
∞	1 281 6	1 644 9

C.5.3 Testing low-modulus (flexible) adhesives

C.5.3.1 General

Low-modulus, flexible adhesives are used at operating temperatures above the glass transition temperature. They are nonlinear elastic under quasi-static loading and capable of accommodating high elongation at break values under these conditions. Such adhesives tend to relax under permanent stress. This can give rise to failure (depending on the type of load and stress level) at a markedly lower strain level than under quasi-static loading. For this reason, the elongation at break after relaxation is to be measured (e.g. ISO 17194).

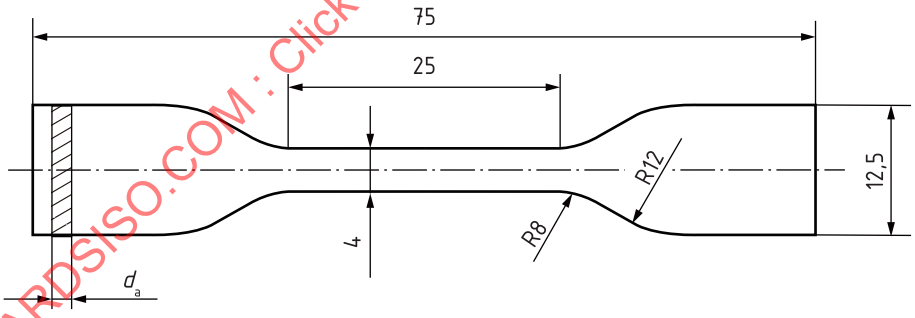
Prolonged constant level static loading results in creep deformation frequently involving a higher strain than with a quickly applied stress and consequential deformation. The creep behaviour shall be determined for creep rupture at constant load, and the maximum permissible strain during a given operating time is specified. Structural provisions may need to be made (e.g. fitting of stops) to rule out any further creep.

C.5.3.2 Determining the modulus of elasticity, the Poisson's ratio and the stress/strain characteristic using adhesive test pieces

Adhesive test pieces can be used to determine basic parameters (modulus of elasticity, the Poisson's ratio, stress-strain characteristic). An example of a test piece form is shown in Figure C.5. Testing can be carried out so that the rate of strain is 0,05 1/s. The rate of testing v may be calculated as follows:

For a test piece having the form shown in Figure C.5 and a parallel length lC = 25 mm, the rate of testing will be 75 mm/min. For other forms of test piece, the rate of testing shall be calculated using Formula (C.2). The rate of testing shall be kept constant throughout the test. Higher rates of testing can have such a great influence on the parameters that loading no longer can be considered as being quasi-static.

Dimensions in millimetres



thickness d_a 2 mm ± 0,5 mm

NOTE As in ISO 37.

Figure C.5 — Type 2 test piece

C.5.3.3 Testing the quasi-static adhesively bonded joint strength for adhesively bonded joints formed with low-modulus adhesives

Testing shall be carried out using single tensile lap-shear strength test pieces (compare ISO 11003-2). The overlap length is between 12 mm and 20 mm. The ratio of the overlap length to the thickness of the adhesively bonded joint line is 4:1, i.e. for an overlap length of 12 mm the thickness is 3 mm and for an overlap length of 20 mm the thickness is 5 mm. The thickness of the joining parts needs to be dimensioned in such a way that a significant bending or failure of the parts to be joined is not to be

expected. The test piece width should be between 20 mm and 35 mm. An example of a test piece form is shown in Figure C.6. The test shear rate $\dot{\gamma}$ is 0,1 s^{-1}.

The rate of testing, *v*, can be calculated using Formula (C.2):

$$v = \dot{\gamma} \times d_0 \tag{C.2}$$

where

v is the test speed/rate of testing;

$\dot{\gamma}$ is the shear rate;

d_0 is the initial adhesive thickness.

For an initial adhesively bonded joint line thickness of d_0 = 3 mm, the rate of testing is 18 mm/min, and for an initial adhesively bonded joint line thickness of d_0 = 5 mm, the rate of testing is 30 mm/min. The rate needs to be kept constant throughout the test.

Dimensions in millimetres

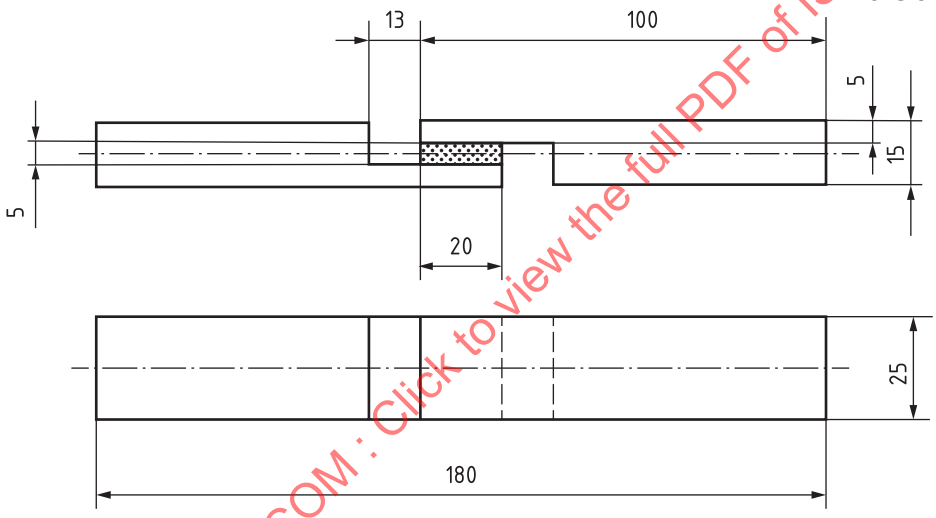


Figure C.6 — Test piece for testing the strength of adhesively bonded joints using a low-modulus adhesive — Example

C.5.3.4 Testing the compression of adhesively bonded joints using low-modulus adhesives

If the design of an adhesively bonded product shows that the adhesively bonded joint is subject to compressive loads, a compression test shall be carried out with cylindrical test specimens as shown in Figure C.7. The strain rate $\dot{\varepsilon}$ is 0,05 1/s. The rate of testing v can be calculated as shown in Formula (C.3):

$$v = \dot{\varepsilon} \times h_0 \tag{C.3}$$

$$v = 0{,}05 \frac{1}{s} \times 10\,\text{mm} = 0{,}5 \frac{\text{mm}}{\text{s}} = 30 \frac{\text{mm}}{\text{min}}$$

where

v is test speed/rate of testing;

$\dot{\varepsilon}$ is the strain rate;

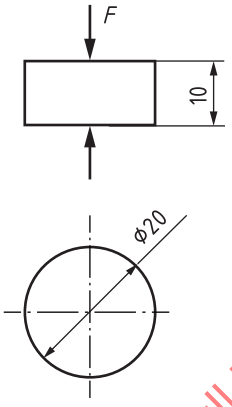
$\dot{\varepsilon} = 0{,}05\ s^{-1}$, to be calculated from $\dot{\varepsilon} = \frac{\Delta}{h_0}$;

Δ is the change of adhesive thickness in mm;

h_0 is the initial thickness of adhesive cylinder = 10 mm (see Figure C.7);

d_0 is the diameter of adhesive cylinder = 20 mm (see Figure C.7).

Dimensions in millimetres



Key

F initial force in N

Figure C.7 — Test piece for compression test

C.5.3.5 Testing the elongation at break after relaxation of adhesively bonded joints using flexible adhesive

The permissible elongation due to a constant deformation of the adhesive shall be determined by subjecting tensile lap-shear test pieces to static loading with constant relative deformation of the adherends, and then applying the load over a long period of time (1 000 h) at a specified shear rate. The elongation at break after relaxation lies below the lowest shear at which there is a cohesive failure of the adhesively bonded joint. It is necessary to ensure that there is no adhesive failure under the relevant temperature and moisture conditions, and surfaces and materials as used in practice. The test piece geometry shall be in accordance with Figure C.7.

C.5.3.6 Testing the creep behaviour of adhesively bonded joints using low-modulus adhesives

Tensile lap-shear tests can be carried out to characterize the creep under permanent static loading. The test piece geometry needs to be in accordance with C.5.3.3. The shear strain shall be determined under varying loads as a function of time and with test conditions that reflect the most unfavourable operating conditions specified in the requirements profile (normally, high temperatures and moisture levels).

The test pieces are loaded uniformly load over a period of three months and the relative displacement of adherends is measured. In References [30] and [54] and parameters J_0, A_0, m and n are used, which are also used in Formulae (C.4) to (C.7).

Creep compliance:

$$J(\tau,t)=J_0+j(\tau)\times t^m \tag{C.4}$$

where

$$j(\tau)=A_0\times\tau^n \tag{C.5}$$

which gives:

$$J=J_0+A_0\times\tau^n\times t^m \tag{C. 6}$$

Relative displacement of adherends:

$$\gamma=J\times\tau \tag{C.7}$$

Using Formulae (C.4) to (C.7), the shear strain under varying loads can be calculated from the test results as a function of time. Preliminary tests can be carried out to determine the creep loads.

C.5.3.7 Testing the fatigue strength of adhesively bonded joints using low-modulus adhesives

Nonlinear elastic or rubber-elastic adhesives require the generation of strain-controlled S-N curves (Woehler curves), as the strain correlates best with the practical conditions. When evaluating the S-N diagrams, the 95 % confidence level and the confidence interval shall be stated. Where the statistical evaluation involves an error that is too large because the time of failure cannot be established with sufficient accuracy, a stress-controlled Woehler curve (see EN 1465[51] and ISO 9664) involving plotting of the initial amplitude following the transient phase can be established. Care is required to ensure that the mean (mean stress or strain) is maintained throughout the test. The test frequency is not allowed to heat the adhesive in the joint by more than 10 K. Fatigue tests are planned and evaluated according to ISO 12107 using test specimens as shown in Figure C.7. Any superimposition due to creep deformation can be investigated using a mean stress other than zero.

C.5.3.8 Measurement of pH value of cured adhesives exposure to moisture

When exposed to water, adhesives can release certain constituents, which give rise to corrosion of the adherend surfaces. Consequential crevice corrosion frequently causes a progressive loss of adhesion and thus degradation of the adhesively bonded joint. Typical examples of this effect are aluminium surfaces, which are only susceptible to corrosion at a certain pH value (depending on the aluminium alloy). Adhesives that, on exposure to moisture, tend to produce an aqueous agent having a pH value conducive to corrosion of the surfaces should not be used.

To establish the pH value, small pieces of cured adhesive are placed in deionized water at a temperature of 40 °C for 30 days. Following that, the pH value is measured; it shall be between pH 6 and pH 8. Two test pieces need to be measured in parallel.

C.5.4 Testing high-modulus (very stiff) adhesives

C.5.4.1 Determining the modulus of elasticity, the Poisson's ratio and the stress/strain characteristic using adhesive test pieces

Adhesive test pieces can be used to determine basic parameters (modulus of elasticity, the Poisson's ratio, stress-strain characteristic) of the adhesive. An example of a test piece form is shown in Figure 1. Testing shall be carried out so that the rate of strain is 0,005 1/s. The rate of testing can be calculated using the equations in C.5.3. Test pieces can have the form according to ISO 37 and to ISO 527-2 or other forms.