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The European
Stainless Steel
Development Association

Adhesive Bonding of Stainless Steels

Materials and Applications Series, Volume 21

Euro Inox

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Cover photos
3M, Neuss (D) (left)
Henkel Loctite, Düsseldorf (D) (right)

Contents

1 Principle

Adhesive bonding is the process of joining materials with the aid of an adhesive – a substance capable of holding materials together by surface attachment. There are two principal types of adhesive bonding: structural and non-structural. Structural adhesive bonding is bonding whereby elements of a structure are fastened one to another with an adhesive. Structural adhesive bonds must be capable of transmitting structural load without loss of structural integrity, within design limits. The major function of adhesives is to join parts. They do this by transmitting stresses from one member to another in such a way that the stresses are distributed more uniformly than can be achieved with conventional, mechanical fasteners. Consequently, adhesives often permit the fabrication of structures that are mechanically equivalent to or stronger than conventional assemblies, at lower cost and weight. Important types of non-structural adhesive bonding include adhesives/sealants and conductive adhesives [1].

For effective bonding, the adhesive must completely wet the surface of each substrate being joined. In addition, strong attractive interactions must form between the adhesive and the substrates [2].

Advantages of adhesive bonding [1, 3]:

- makes a joint almost invisible, enhancing product appearance
- provides uniform distribution of stress and a greater stress-bearing area
- joins thin and thick material of any shape
- joins similar or dissimilar materials
- minimises or prevents electrochemical (galvanic) corrosion between dissimilar materials
- resists fatigue and cyclic loads
- provides joints with smooth contours
- seals joints against a variety of environments
- insulates against heat transfer and electrical conductance
- is free from heat-induced distortions
- dampens vibrations and absorb shocks
- provides attractive strength/weight ratio
- is frequently faster or cheaper than mechanical fastening

Limitations of adhesive bonding:

- does not permit visual examination of the bond area
- requires careful surface preparation, often with corrosive chemicals
- may involve long cure times, particularly where high cure temperatures are not used
- may require holding fixtures, presses, ovens and autoclaves, not usually needed for other fastening methods
- should not be exposed to service temperatures above approximately 180 °C
- requires rigid process control, including emphasis on cleanliness, for most adhesives
- depends, in respect of its useful life, on the environment to which it is exposed

The fact that there are so many variations available in adhesive bonding makes selection of the best adhesive for a particular application more difficult than choosing a mechanical fastening system. Although adhesives are capable of producing structures which are more reliable than those fastened by conventional means, adhesive-bonded structures must be carefully designed and used under conditions which do not exceed the known operational limitations of the adhesive. Limitations include types and magnitudes of stresses (static or dynamic) and environmental factors (temperature, humidity, salt environment, other vapours or liquids) [1].

Although adhesive bonding has been used successfully in façade panels, the information available in this publication focuses on structural adhesive bonding and non-safety-critical applications. The brochure can give general guidelines only and cannot replace consulting the adhesive supplier about the specific properties of his product and the instructions for use.

Adhesive bonding has been successfully used for stainless steel cladding for the façade. Photo: Ebener, Bad Marienberg (D)

2 Theories of adhesion

The actual mechanism of adhesive attachment is not yet fully understood. No single theory explains adhesion in general. The bonding of an adhesive to an object or a surface is the sum of a number of mechanical, physical and chemical forces that overlap and influence each other. As it is not possible to separate these forces from one another, we distinguish between mechanical interlocking (caused by the mechanical anchoring of the adhesive in the pores and uneven parts of the surface), electrostatic forces (concerning the different electronegativities of adhering materials) and the other adhesion mechanisms, dealing with intermolecular and chemical bonding forces that occur at the interfaces of heterogeneous systems.

3 Joint designs

The basic requirement of any joint between two or more components is to carry load effectively. In many cases it should be invisible – i.e. the joint is not seen in the overall structure. In most situations, the adhesive will consist of a material that is different from the adherend it is joining, the chemical and mechanical properties will differ and the resulting joint properties will be influenced by that combination [4].

Adhesive bonding provides great flexibility in design.
Photo: 3M, Neuss (D)

Selection of the correct joint design depends on a wide range of parameters. An adequate joint design ensures durable transmission of the applied loads during the entire service life of the part.

Some design possibilities are presented in Figure 1, overleaf, which shows different kinds of overlap geometries as well as the butt of plane structures [5]. The relatively low strength of the adhesive layer has to be offset by a large bonding area. Stress concentrations in the bond line should be reduced. Peel and cleavage loads therefore have to be minimised by correct design of the part. This can be achieved by positioning joints in areas where only low stresses occur or where mainly shear and compressive stresses are present. Peel and cleavage loads can also be reduced by special joint designs.

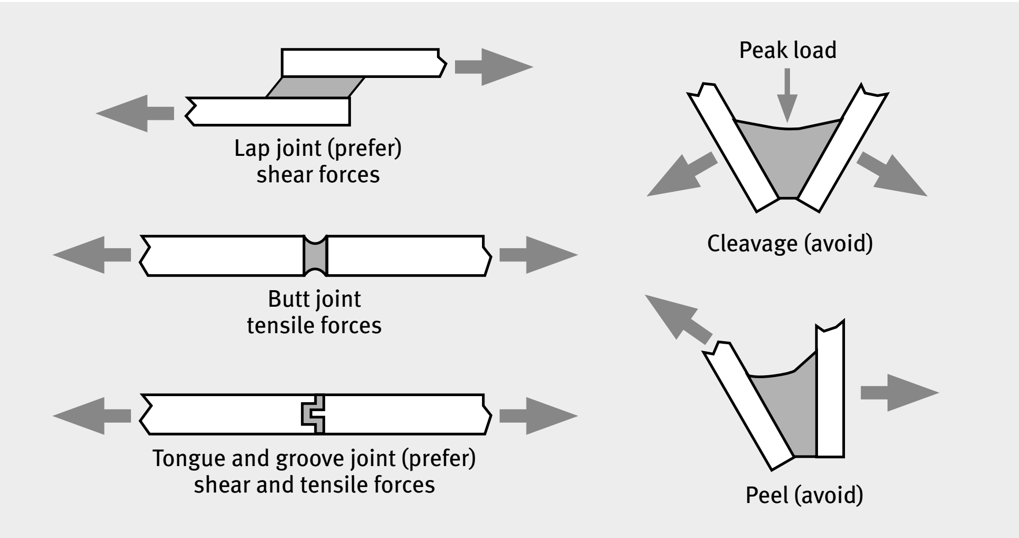


Figure 1. The type of loading applied to the bond and joint orientation [6]

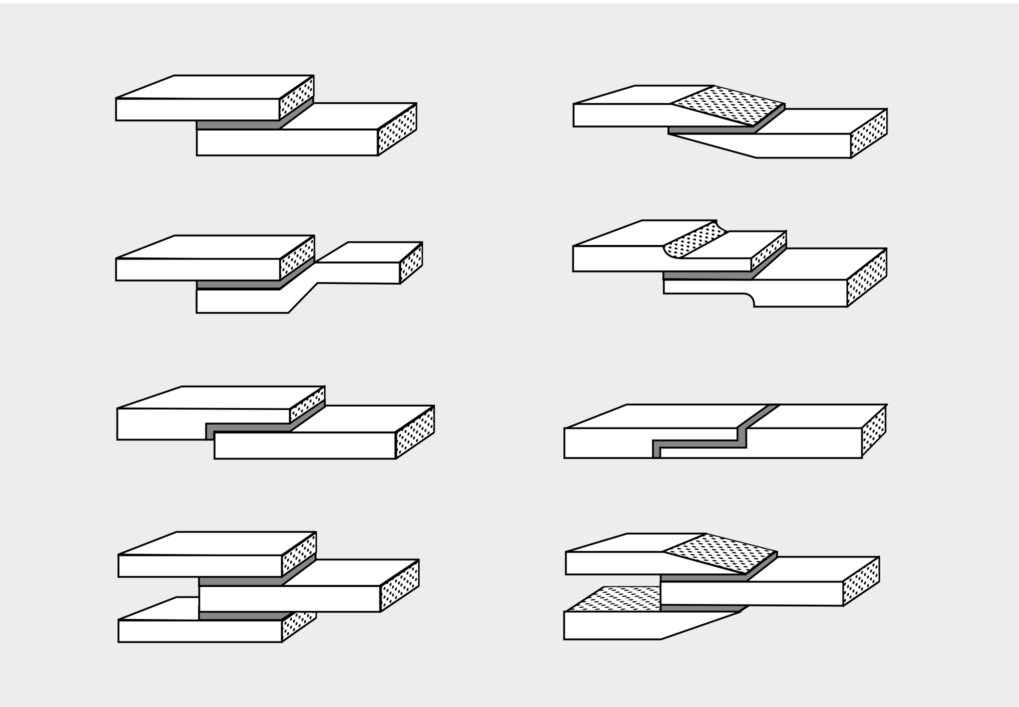


Figure 2. Possible geometries to enhance the bonding area, and/or reduce stress concentrations caused by moments and edge effects [5]

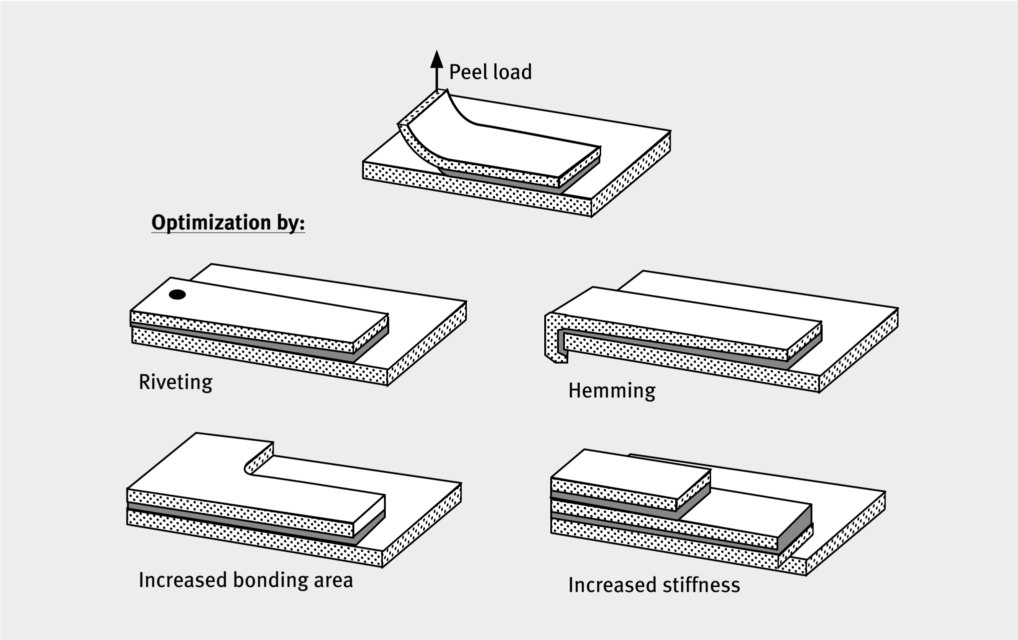


Figure 3. Design optimisation to reduce stress concentrations caused by peel loads [5]

It should be noted that combining two adherends with a considerable mismatch in their coefficient of thermal expansion – for example, stainless steel bonded to aluminium – can result in high thermally induced stresses if the joint is very large and no allowance is made for expansion [4][1].

Because of large bonding areas, stress concentrations are reduced. Photo: 3M, Neuss (D)

[1] For a structure three meters long, assuming zero stresses at the lowest temperature, the dimensional difference between the two skins is approximately 0.6 mm over 30 °C.

4 Surface Treatment

Surface preparation may involve one or all of the following process steps.

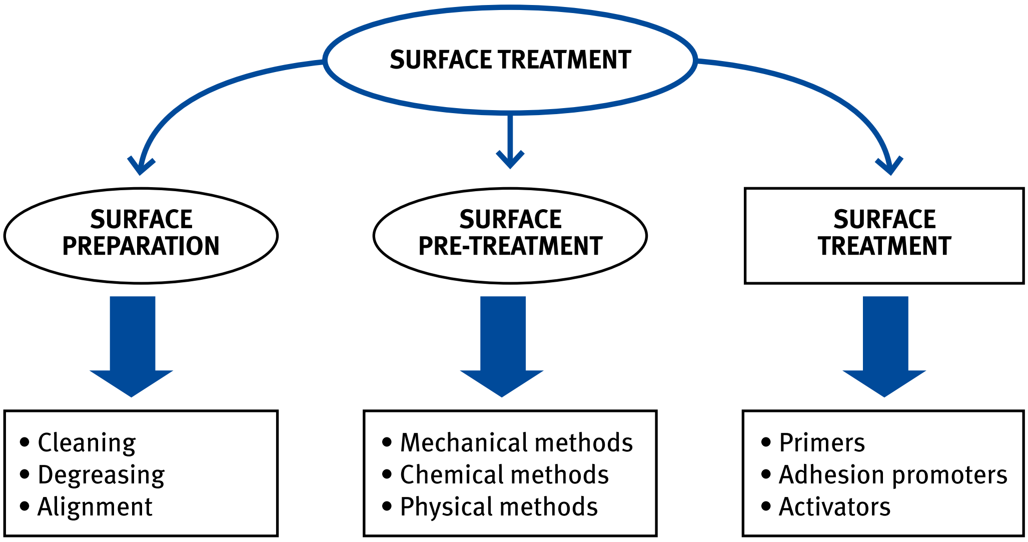


Figure 4. Process steps involved in surface treatment [2]

Surface preparation – the removal of oil, grease and other surface contaminants – i.e. cleaning [2]. With most high-performance adhesives, this step is critical. Even a thumbprint on an otherwise clean surface can prevent the adhesive from spontaneously wetting and spreading. Effective degreasing can be done by washing in trichloroethane [3] or trichoroethylene[2]. The best results are obtained when these are used in the vapour phase, since the liquid which condenses on the metal surface is always clean. If cleaning is carried out with a cloth, this must be white and should be changed as soon as it becomes even slight dirty. If cleaning is performed by immersion in liquid solvent, it is essential to verify the cleanness of the bath, which must contain little or no grease. After cleaning, all residues must be removed from the surface with a detergent, followed by abundant rinsing with pure water [7].

White cloth should be used for cleaning stainless steel surfaces before adhesive bonding. Photo: M. Pyper / Arnold, Friedrichsdorf (D)

[2] Some alternative procedures can be found in *ASTM D2651 – Standard Guide for Preparation of Metal Surfaces for Adhesive Bonding.*

Adhesively bonded profiles proved high structural safety in crash testing. Photo: Technische Universität Kaiserslautern, Kaiserslautern (D)

Surface pre-treatment – includes the use of mechanical, chemical or physical methods to remove strongly absorbed surface layers and activate the surface. Mechanical methods involve the use of handheld sandpaper or hand cleaning tools such as wire brushes. These tools are convenient for removing some loose deposits. Abrasion should always be followed by degreasing, to remove contaminants and loose particles.

Blasting with fine grit is the best method for removing surface deposits (oxide films, tarnish, rust, mill scale and other contaminants) from stainless steel. This method should only be used on structures thick enough to resist distortion [3]. As the compressed air required for blasting is generated in compressors, the presence of small quantities of oil remaining on the surface after blasting cannot be excluded. For this reason, degreasing is essential. It has the additional advantage that any existing shot residues in the surface finish will also be removed [8].

With thinner materials, contaminants should be removed by vapour honing. The method is similar to grit blasting but uses high-velocity water or steam instead of air. If neither method is appropriate, abrasive disks, belts, cloth, medium-grit emery paper or wire brushes can be used [3].

The surface preparation described above – i.e. degreasing alone or degreasing followed by abrasion and further degreasing – is sufficient for most adhesive work. To obtain maximum strength and reproducibility, however, a chemical pre-treatment is required [5, 9].

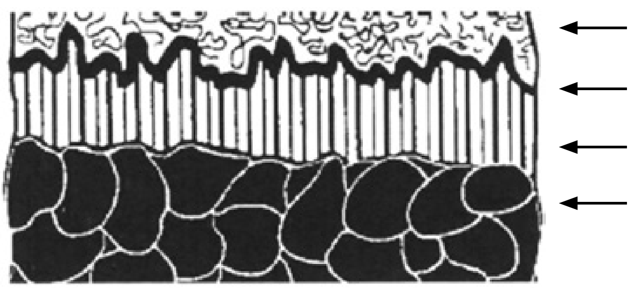


Figure 5. Typical surface layers on a metal substrate [2]

The surface of stainless steel should be carefully prepared before adhesive bonding. Photo: Henkel Loctite, Düsseldorf (D)

In many cases, acid etching may provide a practical surface preparation for bonding. Etchant commonly used with stainless steel is an HNO_3-HF mixture. Various solutions based on sulphuric acid have also been beneficial [3].

Ferritic and austenitic stainless steels [9]

Degrease

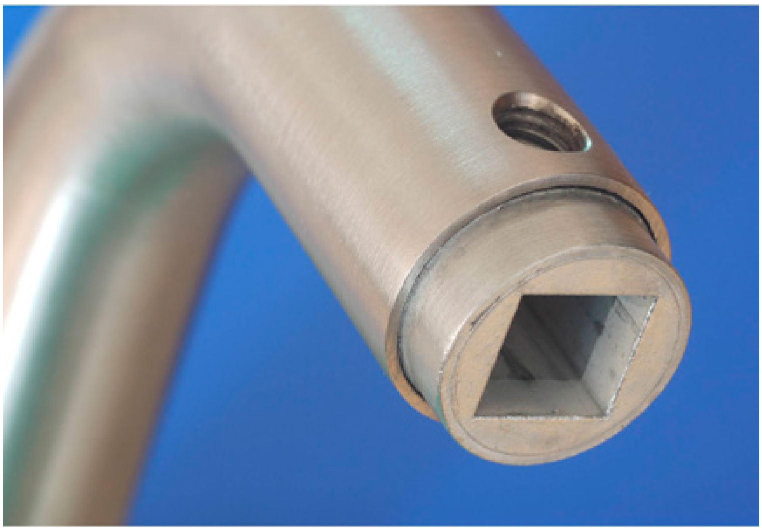
Abrade with non-metallic abrasives (e.g. use emery cloth or grit-blast) and degrease.

To enhance the strength of bonded joints, etch in a solution of:

Oxalic acid[1]	14.0 kg
Concentrated sulphuric acid[2]	12.2 kg
Water	70.0 litres

Immerse for 10 minutes at 85–90 °C, remove from the solution and rinse under clean, cold, running water then brush off the black deposit with a stiff, clean brush.
Dry with hot air.
Bond as soon as possible after pre-treatment.

[1] *Handle with care*
[2] *Specific gravity 1.82*



Adhesive bonding is used for the assembly of door handles. Photo: Hoppe, Stadtallendorf (D)

Good adhesion and durability results are also reported with a highly concentrated mixture of sulphuric acid and sodium dichromate at 80 °C for 60 minutes. The toxicity of these chromate-containing etching mixtures is, however, a major drawback [5].

After acid-bath pickling, anodising can be performed in either nitric acid or a mixture of sulphuric and chromic acid [7]. The anodising is performed at a current density of 0.5 A/dm^2 in a 45–50 volume % nitric acid solution at 50 °C for 60 minutes [5].

Surface treatment. This term refers to the application of adhesion promoters or primers, to improve adhesion of the adhesive and/or protect the surface. Since surface treatment adds another step (and additional costs) to the bonding process, there is a tendency to reduce or even eliminate it entirely. However, in general, the level of surface treatment used should be the minimum that gives a reproducible bonded part with the desired level of performance.

As a general rule, adhesive should be applied immediately after surface treatment. If this is not possible, the treated surface should be protected – for example by covering with kraft paper. Avoid leaving fingerprints on the newly prepared surface. If the substrate is left more than a day before applying, it may be necessary to repeat the surface treatment.

5 Adhesives

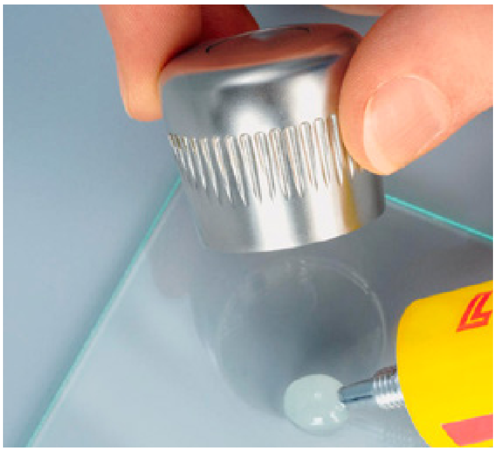
Stainless steel can be successfully bonded to other materials using adhesives such as epoxy resin, acrylic and polyurethane resin. Selection of the appropriate adhesive will depend upon a number of factors, which include the material to be bonded to the stainless steel, the working environment of the composite construction and the type of loading to be resisted [10].

Epoxy adhesive. The curing process of an epoxy adhesive is a reaction between the resin and the hardener. In the case of a one-component (1-K) system, no mixing is required and both, the resin and the hardener are cured at higher temperatures, i.e. above 120 °C. For occasional users of adhesive bonding, or when the bonding is applied to small surfaces only, two component systems are delivered in ready-to-use twin cartridges. Their nozzle brings together the two components in exactly the right proportion and ensures that they are thoroughly mixed right before they are applied. The two-component (2-K) systems also consist of a resin and a hardener. Both parts have to be mixed in the prescribed ratio and will cure at room temperature or elevated temperatures (e.g. 50 °C). The 2-K systems are widely used because they can be stored for long periods of time and do not activate until mixing. Unlike many other adhesives, epoxy adhesives are not solvent based, but cure as the result of a chemical reaction. To avoid brittle behaviour, most modern epoxy adhesives are toughened by using additives.

The nozzle is designed in a way that provides the optimal ratio between resin and hardener. Photo: M. Pyper / Arnold, Friedrichsdorf (D)

Polyurethane adhesives. These are also available in one- and two-component versions. The one-component version cures as a result of a reaction with moisture from the air. Strength properties are low. The selection of additives influences the strength, adhesion, toughness, temperature resistance and curing time [4].

The adhesive manufacturer should be consulted in all cases, but it is also important to contact the stainless steel manufacturer, in order that the appropriate finish can be provided. In general, a coarse finish of the stainless steel enhances mechanical interlocking, but pre-treatment may also be necessary. Modern adhesives are, however, more tolerant of surface films and moisture [10].



Adhesives can join dissimilar materials like stainless steel and glass. Photo: Henkel Loctite, Düsseldorf (D)

Table 1. Selection of adhesives for structural bonding [11]

	With stainless steel	Type of adhesive for semi-structural bonding				
		Silicone	Polymer modified with silane	Polyurethane	Acrylic	Epoxy
Stainless steel	yes	●	●	●	○	●
Carbon steel	yes	●	●	○	○	●
Carbon steel/ painted	yes	●	●	X	○	○
Carbon steel/ galvanised	yes	●	●	X	○	○
Aluminium	yes	●	●	○	○	●
Wood	yes	●	●	○	○	●
Glass/ceramic	yes	●	●	X	○	●
Plastic PVC	yes	●	●	X	X	X
Plastic PA	yes	○	●	X	○	
Plastic PP/PE	no	X	X	X	X	X

● highly recommendable - ○ recommendable - **X** not recommendable

In some cases, proprietary solutions exist that expand the options given in the table. It is advisable to contact the adhesive manufacturers.

Adhesive patches have also been suggested by some adhesive manufacturers. They are double-sided coated tapes on paper, film or tissue. This increases the adhesive's dimensional stability for easy handling and application. They offer many advantages as homogenous distribution of mechanical loads, minimal application training, no investment in major equipment, low weight and good aesthetic of the bond [12]. Due to their thickness, they can take up the difference in thermal expansion when two materials with significantly different coefficients of thermal expansion are used.

Although in the vast majority of applications the adhesive remains hidden within the joint, there are instances where some or all of the adhesive can be visible. In the case of colour (other than transparent), adhesives can take a range of pigments and, if the volume/value is sufficiently large, a wide variety of adhesives can be formulated [5].

Adhesive bonding is a practical solution in building applications, when stainless steel has to be fastened to masonry or natural stone. Photos: Enkolit, Sulz (A)

6 Glossary of terms

Commonly agreed terms are a prerequisite for ensuring quality-determining production flows in industrial processes. The following terms apply to the manufacturing system of "bonding" [8,13].

Adhere	To cause two surfaces to be held together by adhesion
Adhesive	Non-metal, liquid, paste-like or even solid material, joining adherends by means of adhesion forces (surface adhesion) and cohesion forces (inner stability of the adhesive layer)
Adherend	A body bonded or to be bonded to another body
Adhesive layer	An adhesive layer between the adherends, set (cured) or not set
Adherend surface	The glued surface or surface to be glued of an adherend or a bonded joint
Bonded joint	A joint of adherends, obtained by an adhesive
Bonding	The joining of the same or different materials under the application of adhesives
Boundary layer	The zone between the adherend's surface and the adhesive layer where adhesion and bonding strengths are effective
Cure	To change the physical properties of an adhesive by chemical reaction, which may be condensation, polymerisation or vulcanisation. This is usually accomplished by the action of heat and a catalyst, alone or in combination with or without pressure.
Degrease	To remove oil or grease from the adherend's surface
Delamination	The separation of layers in a laminate due to failure of the adhesive, either in the adhesive itself or at the interface between the adhesive and the adherend
Glueline	The space between two adherend surfaces filled with an adhesive layer
Primer	A coating applied to a surface prior to the application of an adhesive to improve the performance of the bond
Sagging	The run-off or flow-off of adhesive from an adherend's surface due to application of excessive or of low-viscosity material
Shelf life, storage life	The period of time during which a packaged adhesive can be stored, under specified temperature conditions, and remain suitable for use
Service condition	The environmental conditions to which a bonded structure is exposed

Setting, curing	Solidification of the liquid adhesive layer
Structural bonding	Structural design with high strength and stiffness, with regular and favourable stress distribution
Time, curing	The period of time during which an adhesive on an adherend or an assembly is allowed to dry, with or without the application of heat or pressure or both
Time, drying	The period of time during which an adhesive on an adherend or an assembly is allowed to dry, with or without the application of heat or pressure or both (also curing time, joint conditioning time and setting time)
Time, joint conditioning	The time interval before the removal of the joint from the conditions of heat or pressure or both necessary to achieve bonding (sometimes called joint aging time)
Time, setting	The period of time during which an assembly is subjected to heat or pressure or both in order for the adhesive to set (also curing time, joint conditioning time and drying time)
Weld bonding	A process in which a joint is formed by spot welding, through an uncured adhesive bond line or by flowing an adhesive into a spot-welded joint
Working life	The period of time during which an adhesive remains suitable for use, after mixing with catalyst, solvent or other compounding ingredients

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