Gerd Habenicht

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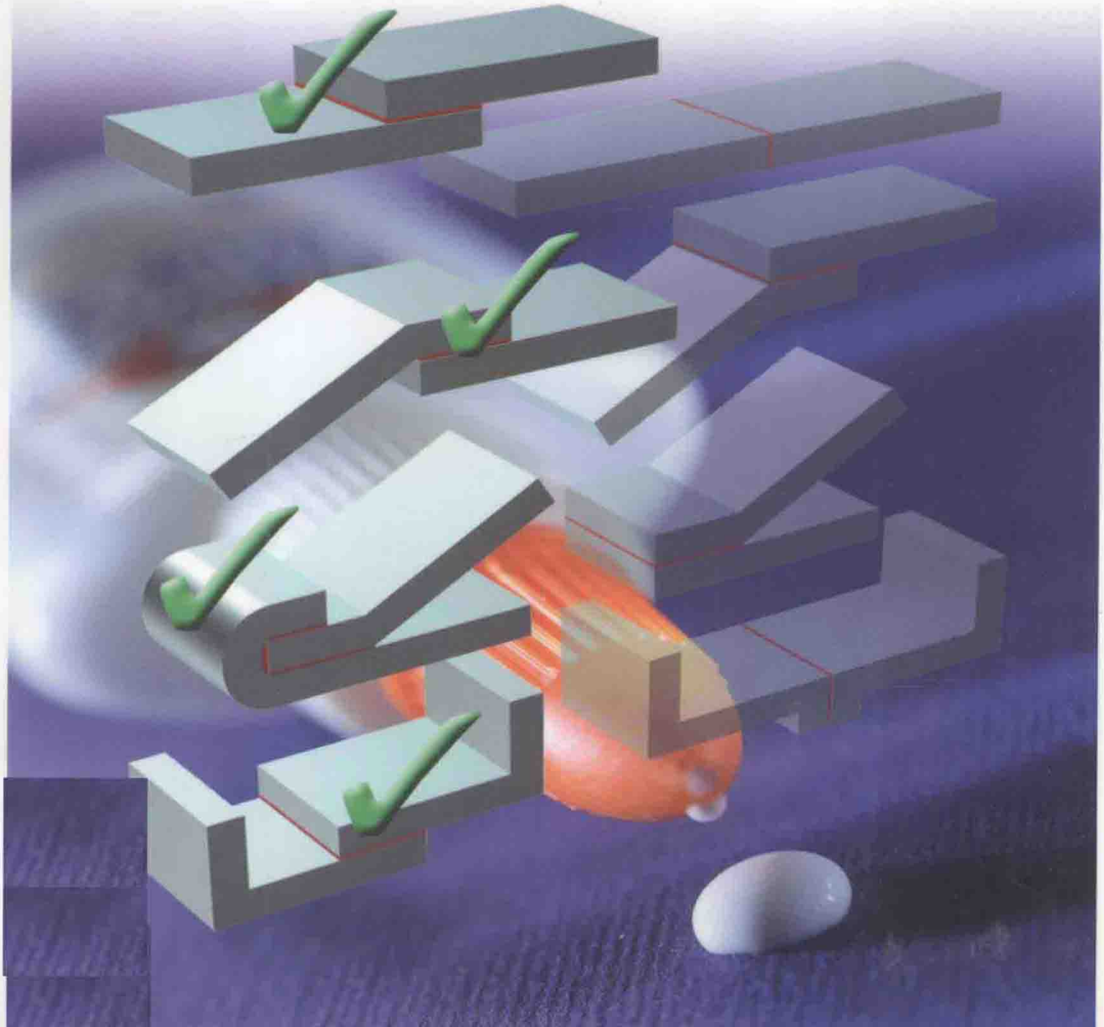
Applied Adhesive Bonding

A Practical Guide for Flawless Results



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A Practical Guide for Flawless Results

Translated by Christine Ahner

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Preface

Bonding especially concerning this book "adhesive bonding", is, without doubt, the oldest of the three joining procedures welding, soldering and bonding, as can be derived from depictions in millennia-old mural paintings. The procedure of adhesive sealing, very closely related to bonding has also been known for ages and had already been applied to the construction of Noah's ark for the sealing of the wooden ship walls with pitch, as narrated in the Bible (First Book of Mose, Chapter 6, verse 14).

Moreover, it has to be mentioned that bonding is the only procedure of the three mentioned that also occurs in nature. For the construction of their honeycombs, for example, bees use their endogenous adhesive secretions together with finest wood fibers to create firmly bonded constructions; swallows affix their nests to masonry; the sundew uses adhesive substances on its tentacles to catch insects as food; and finally even the construction of a spider net is based on the principle of bonding. Man also produces an "adhesive" as a blood component, the fibrinogen, which converts into fibrin through chemical reaction, thus "bonding" tissue components of a wound.

Despite the increasing development of application possibilities for bonding in the remote and recent past, knowledge of adhesives and their processing is still limited and hardly anyone takes into consideration that bonding is a manufacturing method that has to be learned – if it shall be successful, although it seems to be so easy (as it is often represented) that no special knowledge is required to firmly join two materials after the application of the adhesive and the compression of the adherends. Then, if the joint does not hold, it is the fault of the adhesive and the results give rise to doubts as to the reliability of this bonding procedure. However, that such doubts are unfounded is proven by a great number of successful applications with high operational demands, for example, on bonded rotor blades of helicopters or glass panes bonded in the bodywork of motorcars.

This book is intended to provide both basic knowledge in the successful application of bonding in industry, trade or in the private sector and the required information for a professional training in bonding techniques. Especially in the industrial sector, this is a prerequisite indispensable for a quality-oriented mastering of the production system "bonding". The author has addressed himself to the task of describing the essential facts vital for the successful application of bonding in a

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way comprehensible even for nonscientists. This includes explanations of the chemistry of adhesives, the kind of bonding strengths, tips regarding the making of bonded joints, the description of failure possibilities and their avoidance as well as safety measures, tests and structuring principles. For the acquisition of the learning matter it is recommended to work through the book from the beginning instead of randomly reading individual chapters, since particularly with regard to the technical terms and their explanation, a continuing structure was chosen.

May this book reach its aim and impart the knowledge of adhesive-bonding and contribute to the successful application of this joining process.

Wörthsee/Steinebach, December 2008 *Gerd Habenicht*

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1 Introduction

1.1 Bonding as a Joining Process

Adhesive-bonding is assigned to the *materially joined* processes. Bonding processes serve the production of joints of materials of the same kind or of material combinations. The term "materially joined process", which also includes welding and soldering, derives from the fact that the bond occurs by a separately added material, that is

- the adhesive in the case of bonding,
- the welding additive material in the case of welding, and
- solder in the case of soldering.

In addition, there are

- *positive* joints, for example, folding, indented joining;
- *nonpositive* joints, for example, pressing, clamping, screwing, riveting (Figure 1.1).

1.2 Advantages and Disadvantages of Bonding

Compared to some of the joining processes depicted in Figure 1.1, bonding shows remarkable *advantages*:

- The adherends are not weakened by bores as it is the case, for example, when screwing and riveting. Thus power transmission is surface-related instead of spot-related (Figure 1.2).
- There adherends are not stressed by high temperatures, as in welding and, partly, even in soldering. Thus, thermally caused modifications of material properties are prevented, which enables heat-sensitive materials to be joined.
- Adhesive-bonding allows extremely different materials to be joined with themselves or with other materials while retaining their specific characteristics. In the latter case, it is possible to utilize the different advantageous properties for innovative composite structures.

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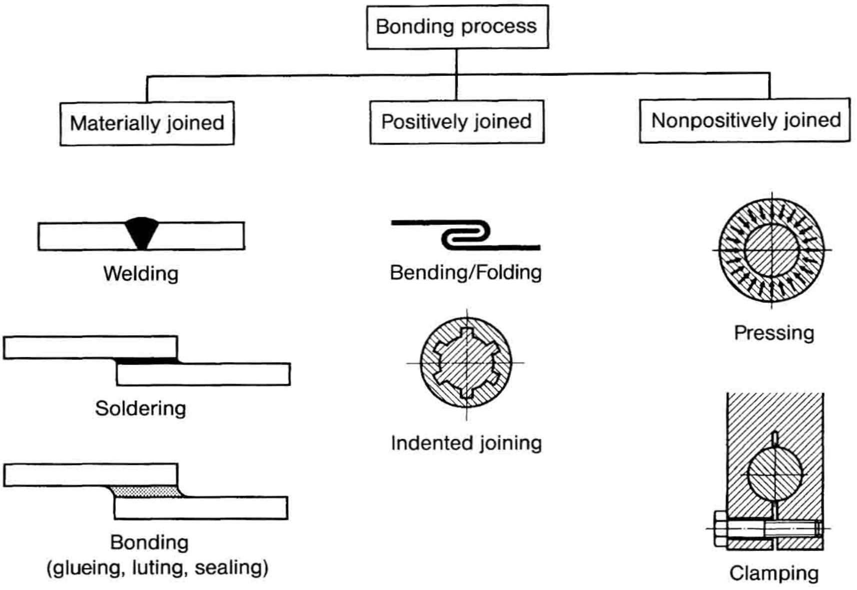


Figure 1.1 Classification of joining processes.

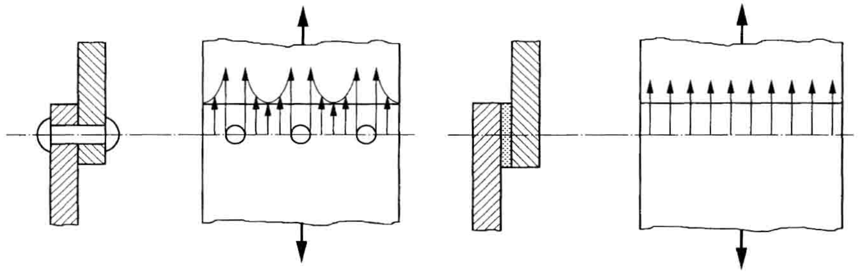


Figure 1.2 Power transmission in riveted (screwed) and bonded joints.

- Bonding as a joining process enables joints of very thin materials (< 500 μm). This procedure is particularly important for the manufacturing of lightweight constructions and the related weight reduction (*inter alia* in aerospace manufacturing). Furthermore, it is the basis of an extremely varied design of film-type laminates in the packaging industry.
- The combination of positive and nonpositive joining processes is important for the optimization of strength, stiffness and corrosion resistance, as the case may be (e.g., folding – bonding in car manufacturing), tightness (e.g., in screw, rivet and spot-welding constructions, shaft-to-collar connections and folds) (Figure 1.1 and 11.5).
- Compared to riveted or screwed connections homogeneous stress distribution when stress-loading (Figure 1.2).

However, these advantages are curtailed by the following *disadvantages:*

- The heat resistance of the adhesive layer is limited. Depending on the basic material of the adhesive, temperatures for continuous stress range between approximately 120 and 300 °C.
- Adhesive layers and their boundary layers towards the adherends' surfaces may be damaged by environmental impacts, such as humidity, which results in a reduction of strength.
- With a few exceptions (e.g., body-in-white manufacturing), the production of bonded joints requires surface treatment of the adherends as an additional production stage.
- In the production of bonded joints, the time required for the relevant reaction kinetics of curing has to be taken into consideration.
- The growing demand for recyclability of industrial products calls for respective design-engineering measures.
- The availability of nondestructive test methods is rather limited.

The essential difference between welding and soldering on the one hand, and bonding on the other hand is the structure of the additive material. Welding additives and solders consist of metals and metal alloys, respectively, which liquefy to a melted mass under the influence of heat (welding torch, soldering iron) and result in a joint after cooling down while integrating parts of the adherends. Adhesives, in comparison, consist of chemical compounds and structures on a basis different from that of metals. These relations are described in Chapter 2.

1.3 Terms and Definitions

Binding terms are a prerequisite to ensure quality-determining production flows in industrial processes. The following terms apply to the manufacturing system of "bonding":

1. Bonding: Joining of same or different materials under the application of adhesives.
2. Adhesive: Nonmetal, 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) (Chapter 6).
3. Adhesive layer: Adhesive layer between the adherends, set (cured) or still not set.
4. Boundary layer: Zone between adherends surface and adhesive layer where adhesion and bonding strengths are effective.
5. Glueline: Space between two adherend surfaces filled with an adhesive layer.
6. Adherend surface: The glued surface or surface to be glued of an adherend or a bonded joint.
7. Bonded joint: Joint of adherends, obtained by an adhesive.

8. Adherend: Body bonded or to be bonded to another body.
9. Setting, curing: Solidification of the liquid adhesive layer.
10. Structural bonding: Structural design with high strength and stiffness resp., with regular and favorable stress distribution (contrary: fixing bonding, e.g., in case of wallpaper) possible through bonding.

Figure 1.3 shows the structure of a single-lap bonded joint with the most important terms.

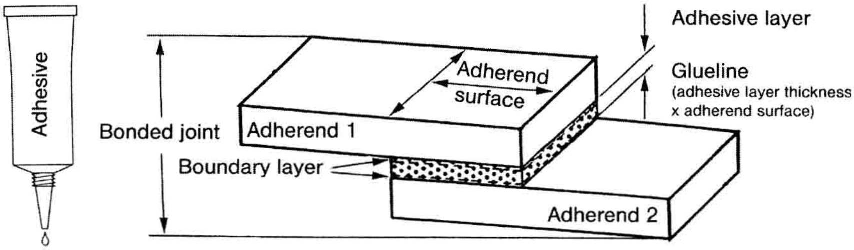


Figure 1.3 Adhesive terms.

Complementary literature to Chapter 1 – general overviews:
[A2, B5, C2, K1, L1, P3].

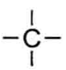
2
Structure and Classification of Adhesives

2.1
Structure of Adhesives

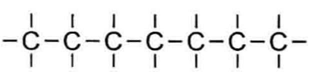
2.1.1
Carbon as Central Element

With regard to their chemical structure, adhesives are to be assigned to the *organic* compounds. In contrast to *inorganic* chemistry, which treats matters of the inanimate nature (e.g., minerals, metals), organic chemistry deals with compounds of carbon as the central element of diverse matters that make up the animate nature (e.g., plant and animal products such as wood, proteins, resins, fats, petroleum).

The special feature of carbon, and thus its dominating position among all known elements, is the fact that an almost unlimited number of compounds with carbon itself and with a multitude of other elements is possible. Each carbon atom (atoms are the smallest "components" characteristic for the properties of an element) shows four "arms" it can "spread" to form a bond. In chemistry, these "arms" are depicted by simple lines and, derived from the Latin word *valentia* = power, strength, they are called *valencies*:



These valencies or bonding possibilities between individual carbon atoms result in long chains,



that may also possess branchings, crosslinked or annular structures:

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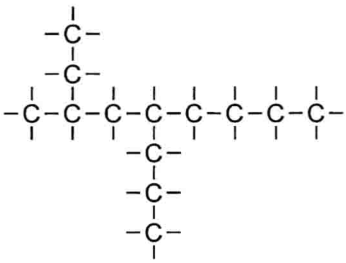
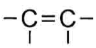
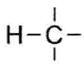
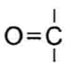


The formation of two bonds between two carbon atoms is possible as well,



furthermore, bonds with other elements exist, as, for example, with

hydrogen 

oxygen 

The individual elements have different numbers of valencies and thus of bonding possibilities, which are predetermined by the structure of their atoms. From these explanations it can be derived that there is a multitude of different organic compounds (more than 1 million) in which above all the elements

	chemical symbols	
carbon	C	(from the Latin word carbo),
hydrogen	H	(from the Latin word hydrogenium),
oxygen	O	(from the Latin word oxigenium),
nitrogen	N	(from the Latin word nitrogenium)

are involved. These organic compounds also comprise by far the largest part of the adhesives. Since in their structure, they are again very similar to the plastics known to us, partly even identical, they are also assigned to the products of the “plastic age”. The modern “synthetic” adhesives became known only about 100 years ago. The first synthetic material with technical significance was “Bakelite”, named after its inventor, the Belgian L. H. Baekeland (1863–1944), a phenol-formaldehyde resin nowadays still applied as synthetic material.

2.1.2 Monomer – Polymer

To further describe adhesives, the explanation of two important technical terms is required (Figure 2.1).

- *Monomer:* This term derives from the Greek language (monos = separate, individual) and indicates the single "components" that combine to polymers due to a chemical reaction.
- *Polymer:* Also of Greek origin (polys = many, meros = portion, part), meaning something like a system of "many parts".

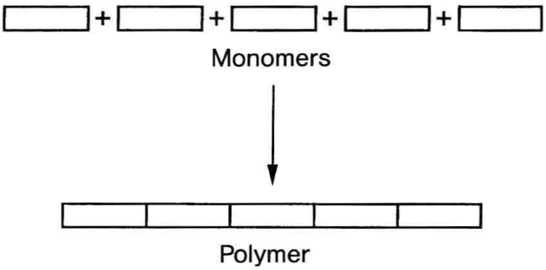


Figure 2.1 Polymer formation from monomers (I).

2.1.3
Polymer Formation

The depiction of the polymer formation can be compared with the arrangement of railway wagons. Due to the "hooks and eyes" at the wagons, any number of wagons (monomers) can connect to a train (polymer) (Figure 2.2).

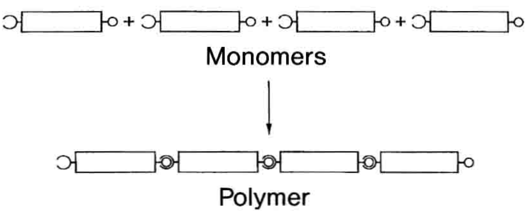


Figure 2.2 Polymer formation from monomers (II).

For this purpose, monomers show a special combination of different elements, so-called "reactive groups" that, instead of the metaphorically called "hooks and eyes", combine with the groups of neighboring monomers by chemical reaction. Thus, "polymer structures" develop from straight and branched or crosslinked chains. These reactive groups will be explained in more detail when the most important adhesives are discussed.

If only a limited number of monomers combine by chemical reaction, then one talks of *prepolymers*, a preliminary stage of polymers, however, still showing reactive groups. They are partly applied in mixtures with similarly structured monomers. To simplify matters, the term monomer continues to be used in this book.