

Jürgen Klungen

Adhesive Bonding in Five Steps

Achieving Safe and High-Quality Bonds

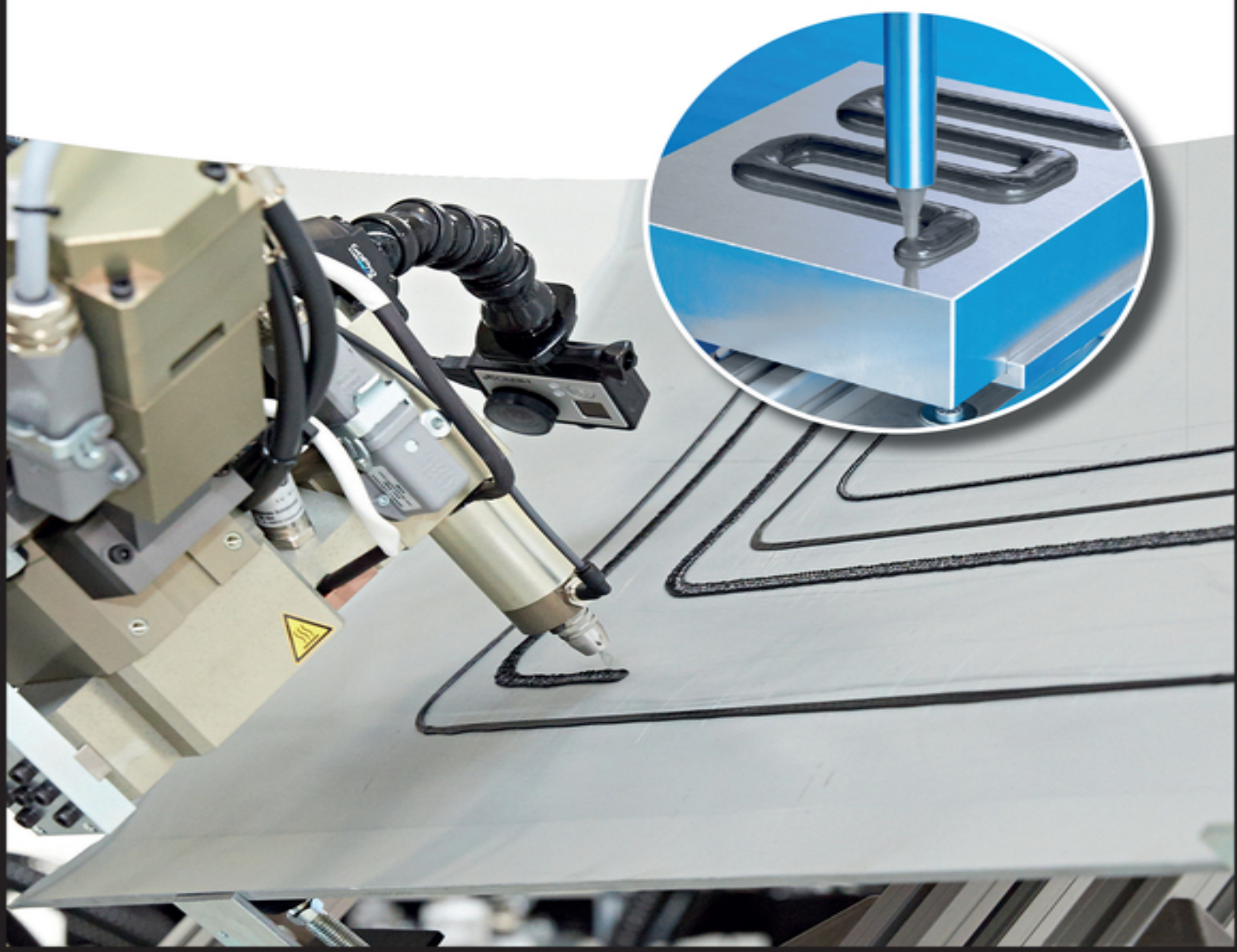


Table of Contents

[Cover](#)

[Dedication](#)

[Title Page](#)

[Copyright](#)

[Preface](#)

[Author Biography](#)

[1 Introduction](#)

[1.1 The *Art* of Adhesive Bonding](#)

[1.2 Adhesives](#)

[1.3 Adhesive Bonds](#)

[1.4 Adhesive Bonding in Industry and Craft](#)

[1.5 An Example for Adhesive Bonding in Nature](#)

[2 History of Adhesive-Bonding Technology](#)

[2.1 First Adhesives](#)

[2.2 Adhesive-Bonding Technology: 1845-1930](#)

[2.3 Adhesive-Bonding Technology: 1930-1960](#)

[2.4 Adhesive-Bonding Technology from 1960 Until Today](#)

[References](#)

[3 Wetting, Adhesion, and Cohesion](#)

[3.1 Introduction](#)

[3.2 Wetting of Surfaces](#)

[3.3 Adhesion to Surfaces](#)

[3.4 Cohesion of Adhesive Layers](#)

[References](#)

[4 Adhesive Bonding in Industry and Craft](#)

[4.1 Introduction](#)

[4.2 The Performance of Standard Adhesives Today](#)

[4.3 Advantages and Disadvantages of Adhesive Bonding](#)

[4.4 Structural and Elastic Bonding](#)

[4.5 Selected Adhesive Systems used in Industry and Craft](#)

[References](#)

[5 The 5 Steps for Achieving Safe and High-Quality Bonds \(Overview\)](#)

[5.1 Introduction](#)

[5.2 Requirements for the *Special Process*](#)

[5.3 Quality Standards](#)

[5.4 The 5-Step Project Management System](#)

[5.5 Gate Reviews](#)

[5.6 Quality Requirements According to DIN 2304](#)

[References](#)

[6 Planning \(Step 1\) – Preparing the Plan and the Project Contract](#)

[6.1 Introduction](#)

[6.2 The Project Plan and Contract](#)

[6.3 Roles of Project-Relevant People](#)

[Reference](#)

[7 Concept \(Step 2a\) – Substrates, their Surfaces, and their Treatment](#)

[7.1 Introduction to Chapters 7 and 8](#)

[7.2 Substrates and their Surfaces](#)

[7.3 Surface Cleaning and Treatment](#)

[References](#)

8 Concept (Step 2b) – Adhesives, their Selection, and Definition of Concepts

8.1 Introduction

8.2 Adhesives for Industry and Craft

8.3 Adhesive Bonding on Metal, Plastic, Glass, and Wood Surfaces

8.4 Loads on Adhesive Bonds

8.5 Adhesive Specification

8.6 Definition of Concepts

References

9 Feasibility (Step 3) – Demonstrating Feasibility and Validation of the Preferred Concept

9.1 Introduction

9.2 Production of Bonded Joints in the Laboratory

9.3 Test Methods for Adhesive Bonds

9.4 Properties of Adhesive Bonds

9.5 Designing Adhesive Bonds

References

10 Development (Step 4) – Establishing a Robust Manufacturing Process Ready for Production

10.1 Introduction

10.2 Adhesive-Bonding Manufacturing Process (Overview)

10.3 Processes for Adhesion Build-up

10.4 Processes for Cohesion Build-up

Reference

11 Start of Production (Step 5)

11.1 Work Done So Far

12 Contemporary Adhesive-Bonding Applications

[12.1 Introduction](#)

[12.2 Adhesive Bonding in Lightweight Construction](#)

[12.3 The Role of Adhesives in Modern Facade Construction](#)

[12.4 Adhesive Bonding on Low-Energy Plastics](#)

[12.5 Adhesive Bonding with Structural 2K Adhesives](#)

[12.6 Inductively Curing Adhesives](#)

[12.7 Adhesive Bonding with High-Performance Acrylic Foam Tapes](#)

[12.8 Closing Wounds with Hotmelt Adhesives](#)

[References](#)

[General References](#)

[Index](#)

[End User License Agreement](#)

List of Tables

Chapter 7

[Table 7.1 Galvanizing processes and applications for galvanized steels.](#)

[Table 7.2 Physical and mechanical properties of aluminum.](#)

[Table 7.3 Mechanical properties of plastic material compared to metals.](#)

[Table 7.4 Surface energies of selected low- and high-energy materials used f...](#)

[Table 7.5 Evaporation ratios, boiling points, and flash points of some solve...](#)

[Table 7.6 Cleaning ability of organic solvents for plastic surfaces.](#)

[Table 7.7 Overview of mechanical surface treatment methods and their suitability...](#)

[Table 7.8 Overview of physical surface treatment methods and their suitability...](#)

Chapter 8

[Table 8.1 Adhesive-bonding properties of plastics as a function of their polymer...](#)

Chapter 9

[Table 9.1 Comparison of the characteristic features of structural and elastomeric adhesives...](#)

Chapter 10

[Table 10.1 Typical viscosity values for commonly used materials and adhesives...](#)

[Table 10.2 Dependence of water vapor contents \(in g/m³\) on temperature and relative humidity...](#)

List of Illustrations

Chapter 1

[Figure 1.1 The creation of safe and high-quality adhesive joints through knowledge...](#)

[Figure 1.2 Structure of an adhesive bond with metal substrates, in which the adhesive...](#)

[Figure 1.3 Detailed structure of a metal surface and removal of the adsorbed contaminants...](#)

[Figure 1.4 Formation of a joint by using the classical methods and adhesive ...](#)

[Figure 1.5 Mussels adhesive bonded to a wooden pile in the North Sea near Do...](#)

Chapter 2

[Figure 2.1 Birch tar produced in a one-pot process.](#)

[Figure 2.2 Patent for a *self-adhesive plaster* that releases active ing...](#)

[Figure 2.3 Roll of *Leukoplast* from the 1930th found in a Red Cross first-aid...](#)

[Figure 2.4 Package of *Hansaplast CLASSIC* as sold today.](#)

[Figure 2.5 The first application of *masking tape* at a automobile manufacture...](#)

[Figure 2.6 Metal container with *Scotch*[®] *Cellophane Tape* from the 1950s....](#)

[Figure 2.7 *UHU*[®] - the all-purpose adhesive as it is SO...](#)

[Figure 2.8 The first *tesafilm*[®] product of 1936.](#)

[Figure 2.9 A roll of *Duct Tape* as it is widely used today made of a PE-coate...](#)

[Figure 2.10 A selection of *Post-it*[®] products as they are sold toda...](#)

[Figure 2.11 A roll of *acrylic foam tape VHB*[™] as it is sold today.](#)

Chapter 3

[Figure 3.1 Bad, good, and excellent wetting of a liquid on a solid surface....](#)

[Figure 3.2 Schematic representation of the parameters for the Young equation...](#)

[Figure 3.3 Surface tension allows a paper clip made of a silicone-coated iron...](#)

[Figure 3.4 Good wetting of the low-energy liquid *n*-heptane on the high-energy...](#)

[Figure 3.5 Determination of the critical surface tension \$\sigma_{crit}\$ of a solid us...](#)

[Figure 3.6 Molecular interactions of the adhesive polymer chains for the cre...](#)

[Figure 3.7 Interactions of permanent \(a\) and induced dipoles \(b\).](#)

[Figure 3.8 Formation of hydrogen bonds between the adhesive and the material...](#)

Chapter 4

[Figure 4.1 Demonstration of the performance of a *standard* 2K epoxy adhesive....](#)

[Figure 4.2 Form-fit \(transverse to the rail\) and force-fit \(longitudinal to ...](#)

[Figure 4.3 Stress distribution in riveted \(non-uniform\) and adhesive bonded ...](#)

[Figure 4.4 A limited range of adhesives for small bonding applications in in...](#)

[Figure 4.5 Adhesive strengths and elongations of adhesive classes used in in...](#)

[Figure 4.6 Deformation behavior of adhesive joints in structural and elastic...](#)

[Figure 4.7 Cyanoacrylate adhesives as used in small bottles with different v...](#)

[Figure 4.8 Manual hotmelt adhesive gun with the adhesive in the form of disp...](#)

[Figure 4.9 User-friendly on-demand mixing and dispensing system with double ...](#)

[Figure 4.10 A roll of acrylic foam tape as used in numerous applications....](#)

[Figure 4.11 Use of acrylic foam tape for the attachment of self-adhesive EPD...](#)

[Figure 4.12 Structure of a high-strength re-closable fastening system consis...](#)

[Figure 4.13 Duct tape saves lives by helping to adjust the CO₂ filter of the...](#)

Chapter 5

[Figure 5.1 The 5-step project management system for the development of a bon...](#)

[Figure 5.2 Part 1 of the management process with major results obtained afte...](#)

[Figure 5.3 Part 2 of the management process with major results obtained afte...](#)

[Figure 5.4 Core elements of DIN 2304.](#)

Chapter 6

[Figure 6.1 Major tasks and accomplishments of the planning phase.](#)

Chapter 7

[Figure 7.1 Major tasks and accomplishments of Step 2a.](#)

[Figure 7.2 Atomic structure of metals.](#)

[Figure 7.3 Heavily corroded iron parts from the First World War \(1914-1918\),...](#)

[Figure 7.4 Classification of ferrous materials.](#)

[Figure 7.5 Classification of steel according to chemical composition and qua...](#)

[Figure 7.6 Galvanizing processes for the treatment of steel surfaces.](#)

[Figure 7.7 Influence of deformation on strength in the case of brittle \(a\), ...](#)

[Figure 7.8 Structure of thermoplasts \(in this case semi-crystalline\) \(a\), th...](#)

[Figure 7.9 Viscous behavior represented by the Newton element \(a\) and linear...](#)

[Figure 7.10 Viscoelastic behavior represented by the Maxwell model \(a\) and t...](#)

[Figure 7.11 Viscoelastic behavior represented by the Burger model.](#)

[Figure 7.12 Structure of quartz crystal \(crystalline\) \(a\) and glass \(amorpho...](#)

[Figure 7.13 Preparation, treatment, and post-treatment of surfaces.](#)

[Figure 7.14 Adhesive \(a\), mixed \(b\), and cohesive failure \(c\) of a bonded jo...](#)

[Figure 7.15 Structure of metal surfaces \(schematic and not to scale\).](#)

[Figure 7.16 Microstructure of a three-dimensional grinding fleece with alumi...](#)

[Figure 7.17 Manual Pyrosil[®] flame treatment on a glass surface.](#)

[Figure 7.18 Illustration of a corona system used for film treatment \(schemat...](#)

[Figure 7.19 Influence of plasma treatment on the chemistry and surface energ...](#)

[Figure 7.20 Representation of an atmospheric plasma system \(schematic and no...](#)

[Figure 7.21 Atmospheric plasma treatment of a metal surface.](#)

Chapter 8

[Figure 8.1 Major tasks and accomplishments of step 2b.](#)

[Figure 8.2 Adhesive classification according to the curing mechanism.](#)

[Figure 8.3 Adhesive classification according to the number of components.](#)

[Figure 8.4 Dispensing a cyanoacrylate adhesive onto an EPDM seal used for ca...](#)

[Figure 8.5 The curing penetration of a moisture-curing 1K PU adhesive depend...](#)

[Figure 8.6 Old cut-open adhesive layer before re-application of 1K PU adhesi...](#)

[Figure 8.7 Application of a 1K PU adhesive to an old cut-open adhesive layer...](#)

[Figure 8.8 Application of a molten hotmelt adhesive onto a wooden surface....](#)

[Figure 8.9 Manual hotmelt adhesive gun and the corresponding adhesive in the...](#)

[Figure 8.10 Temperature profile during the processing of hotmelt adhesives....](#)

[Figure 8.11 Temperature ranges when melting, applying, and joining hotmelt a...](#)

[Figure 8.12 Development of adhesive strength of a moisture-curable hotmelt P...](#)

[Figure 8.13 Radiation source for manual curing of photoinitiated adhesives....](#)

[Figure 8.14 Photoinitiated curing of a glass-steel adhesive bond with an acr...](#)

[Figure 8.15 Screw locking performed by an anaerobic adhesive.](#)

[Figure 8.16 A selection of PSA products used in industry, craft, and househo...](#)

[Figure 8.17 Areas of the storage modulus \$G\$ in a typical PSA curve relevant ...](#)

[Figure 8.18 Organization principle of thermoplastic block-copolymers with po...](#)

[Figure 8.19 The three types of thermoplastic block copolymers found in PSAs....](#)

[Figure 8.20 Tools for the application of PSA tapes.](#)

[Figure 8.21 A pad of removable sticky notes for labeling with information....](#)

[Figure 8.22 Duct tape made of a PE-coated adaptable fabric with natural-rubb...](#)

[Figure 8.23 Example demonstrating the maximum expansion capacity of a typica...](#)

[Figure 8.24 2K adhesive systems.](#)

[Figure 8.25 Dependence of adhesive strength on the mixing ratio of a 2K epox...](#)

[Figure 8.26 Hot-dip-galvanized steel railing at the bridge over the Neckar i...](#)

[Figure 8.27 Reaction mechanisms of coupling agents with the glass surface an...](#)

[Figure 8.28 Loads on adhesive bonds.](#)

[Figure 8.29 Internal loads due to thermal expansion of similar or identical ...](#)

[Figure 8.30 Internal loads due to thermal expansion of dissimilar substrates...](#)

[Figure 8.31 Shrinkage of adhesive layers during curing of heat-curable adhes...](#)

[Figure 8.32 Formation of rust on a steel surface by reaction of atmospheric ...](#)

[Figure 8.33 Definition of the parameters relevant for the adhesive specifica...](#)

[Figure 8.34 Improvement of bonding performance and aging resistance of metal...](#)

Chapter 9

[Figure 9.1 Major tasks and accomplishments of Step 3 \(feasibility\).](#)

[Figure 9.2 Preparation and execution of the production of an adhesive joint ...](#)

[Figure 9.3 Personal protective equipment required for the production of an a...](#)

[Figure 9.4 Safety glasses according to EN 166 required for adhesive-bonding ...](#)

[Figure 9.5 Protective nitrile rubber gloves according to EN 374 required for...](#)

[Figure 9.6 Breathable knitted gloves according to EN 388 with PU coatings fo...](#)

[Figure 9.7 Manual surface preparation, treatment, and post-treatment suitabl...](#)

[Figure 9.8 Abrasive fleece hand pads in the grades very fine \(a\) and ultra f...](#)

[Figure 9.9 Aluminum surface before \(a\) and after grinding \(b\) with an abrasi...](#)

[Figure 9.10 Bead application of high-viscosity adhesives in triangular- and ...](#)

[Figure 9.11 Common forms for manual processing of 2K epoxy adhesives in the ...](#)

[Figure 9.12 Production of very small quantities of 2K adhesive for laborator...](#)

[Figure 9.13 User-friendly on-demand mixing and dispensing systems for one-st...](#)

[Figure 9.14 Course of viscosity/adhesive strength during application, curing...](#)

[Figure 9.15 Processing of 2K acrylate adhesives using the *A-B process*...](#)

[Figure 9.16 Dependence of adhesive strength and curing time on the hardener ...](#)

[Figure 9.17 Technological test methods for adhesive bonds, aging conditions,...](#)

[Figure 9.18 Overlap shear test to determine the shear stress \(adhesive stren...](#)

[Figure 9.19 Course of shear stress as a function of the shear strain \$\tan \gamma\$](#)

[Figure 9.20 Specimen geometry and alignment of the force in the tensile test...](#)

[Figure 9.21 Specimen geometry and alignment of the forces during 90° \(a\) and...](#)

[Figure 9.22 Course of the peel force as a function of peel distance and the ...](#)

[Figure 9.23 Specimen geometry and alignment of the forces during the cleavag...](#)

[Figure 9.24 Specimen geometry and alignment of the forces during the 3-point...](#)

[Figure 9.25 Specimen geometry for the wedge test with crack propagation dire...](#)

[Figure 9.26 Types of composite fractures that can occur in bonded specimens ...](#)

[Figure 9.27 Deformation behavior of elastic, viscous, and viscoelastic mater...](#)

[Figure 9.28 The representation and relationships between the complex modulus...](#)

[Figure 9.29 Typical DMTA curves of an adhesive showing the storage modulus \$G\$](#)

[Figure 9.30 Ranges of dependence of adhesive strength on temperature.](#)

[Figure 9.31 Course of storage modulus and position of glass transition range...](#)

[Figure 9.32 Thermomechanical ranges of PSAs.](#)

[Figure 9.33 Course of the storage modulus of a PSA meeting the Dahlquist cri...](#)

[Figure 9.34 Effects of adding tackifiers to elastomers on the storage modulu...](#)

[Figure 9.35 Determination of the shear strain \$\tan \gamma\$ of an adhesive from the ...](#)

[Figure 9.36 Shear stress-strain diagram of a bonded joint.](#)

[Figure 9.37 Simplified representation of reversible deformation \(creep\) by a...](#)

[Figure 9.38 The three phases of creep and flow behavior of bonded joints und...](#)

[Figure 9.39 The four types of creep and flow behavior of bonded joints under...](#)

[Figure 9.40 Simplified representation of the creep behavior of an adhesive l...](#)

[Figure 9.41 Creep diagram of an adhesive without permanent irreversible plas...](#)

[Figure 9.42 Creep diagram of an adhesive with permanent irreversible plastic...](#)

[Figure 9.43 Stress relaxation diagram of an adhesive with residual stress af...](#)

[Figure 9.44 Factors influencing the functionality of an adhesive bond.](#)

[Figure 9.45 Position of the yield strength at 0.2% permanent deformation \(\$R_{p...}\$](#)

[Figure 9.46 Increase the load-bearing capacity of a joint by using single-la...](#)

[Figure 9.47 Dependence of adhesive strength on the overlapping length in the...](#)

[Figure 9.48 Influence of the overlap length on the failure load \(\$F\$ \) represen...](#)

[Figure 9.49 Influence of overlap width on the failure load \$F\$.](#)

[Figure 9.50 Influence of adhesive layer thickness on the adhesive strength \$\tau\$](#)

[Figure 9.51 Stress distribution in the adhesive bond during peel \(a\) and she...](#)

[Figure 9.52 Avoidance of bending moments by a two-shear connection, allowing...](#)

[Figure 9.53 Cleavage load acting on an adhesive bond.](#)

[Figure 9.54 Load-bearing capacity of an adhesive bond after reduction of its...](#)

[Figure 9.55 Joining two stainless-steel plates \(example 1\). Question mark me...](#)

[Figure 9.56 Joining a GFR plastic sheet to a stainless-steel frame \(example ...](#)

[Figure 9.57 Joining of a glass pane to an aluminum frame \(example 3\).](#)

Chapter 10

[Figure 10.1 Increase of maturity of the concept design from first sketching ...](#)

[Figure 10.2 Major tasks and accomplishments of Step 4 \(development\).](#)

[Figure 10.3 Manufacturing process chain from component feeding to removal of...](#)

[Figure 10.4 Process objectives and process steps for the production of adhes...](#)

[Figure 10.5 Viscosity curves of Newtonian, structural-viscose, and dilatant ...](#)

[Figure 10.6 Principle of a metering and mixing system for 2K adhesive system...](#)

[Figure 10.7 Large-scale 2K application system according to the principle ill...](#)

[Figure 10.8 Automatic application and curing system for electronic component...](#)

[Figure 10.9 Methods for partial- and full-surface adhesive application.](#)

[Figure 10.10 Static mixers for 50 ml cartridges according to the Sulzer \(a\) ...](#)

[Figure 10.11 Mixing coils of static mixers according to the Kenics \(a\) and S...](#)

[Figure 10.12 Adhesive inlet of components A and B into a mixer according to ...](#)

Chapter 11

[Figure 11.1 Essential tasks to be accomplished for the start of production....](#)

Chapter 12

[Figure 12.1 Bonded components after a crash test in which the joint bonded w...](#)

[Figure 12.2 Trailer assembled with the help of a high-performance acrylic fo...](#)

[Figure 12.3 Glass facade in Brazil, bonded with a high-performance acrylic f...](#)

[Figure 12.4 Pendulum impact test applied on a glass construction, bonded wit...](#)

[Figure 12.5 Use of self-adhesive transfer tapes for bonding controls in the ...](#)

[Figure 12.6 Art object *Uelfe Display* bonded with 2K structural adhesive.](#)

[Figure 12.7 Typical application of a 2K acrylate adhesive \(bonding plastic p...](#)

[Figure 12.8 Inductive heating of an adhesive composite in the laboratory wit...](#)

[Figure 12.9 Dependence of the handling strength of the new 2K adhesive on th...](#)

[Figure 12.10 Bonding a rear-view camera with a high-performance acrylic foam...](#)

Figure 12.11 Touch screen of a handheld auto-refractometer bonded with die-c...

This book is dedicated to Prof. Dr. Walter Brockmann, a great scientist, teacher, and promoter of adhesive-bonding technology, who unfortunately passed away far too early in June 2011 at the age of 72.

In various positions, Prof. Brockmann significantly advanced the corresponding research and application engineering activities in Germany and Europe over decades. Before his death, he had headed the Materials and Surface Engineering Group (AWOK) at the University of Kaiserslautern, Germany, since 1990. Prior to that, he worked for more than 20 years as a scientist and department head at the Fraunhofer Institute for Applied Materials Research (IFAM) in Bremen, Germany.

As a co-founder of the “European Adhesion Conference” (EURADH), he has significantly promoted European and international cooperation in the field of adhesive-bonding technology and with his significant involvement in the initiation of the “World Congress on Adhesion and Related Phenomena” (WCARP) Prof. Brockmann strongly supported the globalization of research in adhesive-bonding technology.

His open, uncomplicated, and friendly manner, coupled with his boundless knowledge and experience, has enabled Prof. Brockmann to convey the many aspects and advantages of adhesive-bonding technology to me and many others, including R&D managers, scientists, students, and users in industry. In my case, he triggered a great enthusiasm for this technology that remains unbroken to this day.

Adhesive Bonding in Five Steps

Achieving Safe and High-Quality Bonds

Dr. Jürgen Klungen

WILEY-VCH

Author***Dr. Jürgen Klungen***

41366 Schwalmatal

Germany

Cover Design: SCHULZ Grafik-Design**Cover Image:** Atlas Copco

All books published by **WILEY-VCH** are carefully produced. Nevertheless, authors, editors, and publisher do not warrant the information contained in these books, including this book, to be free of errors. Readers are advised to keep in mind that statements, data, illustrations, procedural details or other items may inadvertently be inaccurate.

Library of Congress Card No.: applied for

British Library Cataloguing-in-Publication Data A catalogue record for this book is available from the British Library.

Bibliographic information published by the Deutsche Nationalbibliothek

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at <<http://dnb.d-nb.de>>.

© 2022 WILEY-VCH GmbH, Boschstr. 12, 69469 Weinheim, Germany

All rights reserved (including those of translation into other languages). No part of this book may be reproduced in any form - by photoprinting, microfilm, or any other means - nor transmitted or translated into a machine language without written permission from the publishers. Registered names, trademarks, etc. used in this book, even when not specifically marked as such, are not to be considered unprotected by law.

Print ISBN: 978-3-527-34914-2

ePDF ISBN: 978-3-527-83224-8

ePub ISBN: 978-3-527-83225-5

oBook ISBN: 978-3-527-83226-2

Preface

There is no doubt that adhesive-bonding technology is one of the key technologies for manufacturing products in the twenty-first century. The reasons for this are the need to simplify production processes, implement modern and innovative design concepts, reduce costs in the manufacture of products, and make greater use of lightweight construction methods to save energy.

However, the bonding process is a “special process” that cannot be inspected without destroying the products it creates, the bonded components. In addition, its design is decisively, indeed almost exclusively, responsible for the quality of the bonded joint. The reason is that in adhesive bonding, unlike alternative joining processes such as welding, screwing, and riveting, the joining agents used here – the adhesives – are not present in their final form, but are physically and/or chemically modified by the user during the manufacture of the components. To guarantee the required product quality, the process used for this purpose must be developed in a detailed, careful, and resilient manner, from the initial assessment of the materials involved to the successful completion of the bonded joints.

This book is intended for engineers, chemists, scientists, technicians, foremen, and students who are charged with the development of such a process or who, for other reasons, would like to inform themselves about the necessary prerequisites and measures for the production of an optimally bonded component. It describes in detail the steps required to set up an adhesive-bonding process to produce a high-quality component. This is done with the help of a specially developed 5-step project management

system tailored to adhesive-bonding technology, which accompanies the development team from the initial idea for the adhesive-bonding process to its successful introduction into production. The requirements of DIN 2304 – a standard developed specifically for adhesive-bonding technology – are observed and ensure the establishment of suitable organizational structures in the manufacturing plant, the design of the environment required for adhesive-bonding technology, a high-quality production facility, and execution in line with quality standards. The tools and quality techniques required for planning and executing the 5-phase management process are provided by the Six Sigma methodology.

When working through the reading, the reader is taken by the hand, so to speak, and guided step by step through this process. Right at the beginning of the book – in the concept stage – the necessary basic knowledge of adhesive-bonding technology, technical information about the substrates used, the methods for treating their surfaces, and knowledge about the properties and behavior of adhesives are provided in detail. This enables the reader to outline bonding concepts as a basis for the further development steps.

In the subsequent feasibility demonstration step, practical work begins in the laboratory, initially focusing on the production and testing of laboratory samples of all outlined concepts. The aim here is to identify the most suitable candidate and then validate it after preparation and intensive testing of the corresponding practical components. At the end of the feasibility step, a concept validated for the stresses occurring in practical use is available, which is described in detail by the substrates to be used, the required surface treatment, the most suitable adhesive, and the necessary manufacturing steps for producing the bonded component.

The goal of the development step following the feasibility stage is to establish a robust process for manufacturing the already-validated bonded component. To this end, once the manufacturing process suitable for production scale has been outlined, its suitability in principle must be demonstrated by appropriate pilot runs using statistical methods. Subsequently, after the standards for production and quality control have been developed and the personnel performing the work on the production machines have been trained and instructed, production of the bonded component can be started.

This book is intended to help strengthen the already-outstanding status of adhesive-bonding technology as a modern joining method. To this end, it enables users in industry and the trades to plan the process of bonding components systematically and thus to make it highly efficient. Thus, the application of the proposed management system enables the reproducible production of safe and high-quality bonded joints.

I would like to thank Wiley-VCH for their willingness to publish the book and for their great help in realizing it. I would also like to thank Prof. Dr. Paul Ludwig Geiß, head of the Materials and Surface Engineering Group in the Department of Mechanical Engineering (AWOK-Arbeitsgruppe Werkstoff- und Oberflächentechnik) at the University of Kaiserslautern, for the interesting and stimulating discussions on the conception of the book. I hope that it will be of great help to many users in industry and trade in the development of appropriate bonding processes and thus make a significant contribution to the further positive development of bonding technology in the twenty-first century.

Schwalmtal, Germany
January 2022

Dr. Jürgen Klingen

Author Biography

Dr. Jürgen Kligen studied chemistry at the University of Duisburg, Germany, and received his doctorate from Prof. Robert Gillard at the University of Wales (Department of Applied Chemistry) in the field of crosslinking of polyisoprene-based adhesives.

For more than 35 years, he held various positions in research, development, and application engineering for the company 3M Deutschland GmbH, 1 year in corporate research in St. Paul, Minnesota, USA, where he worked on new high-performance adhesive systems for the European market. He received the 3M Corporate Circle of Technical Excellence Award for his research in this area. From 1996 to 2017, Dr. Kligen headed 3M's European Corporate Materials and Process Laboratory in Neuss, Germany, where he was responsible for technology development of new adhesives, tapes, films, coatings, and polymer processing for Europe.

Since the end of 2017, he has been working as a consultant for the development of bonding processes in industry and trade. Dr. Kligen is co-author of two technical books and sole author of one technical book as well as holder of several patents in the field of adhesive-bonding technology.

1 Introduction

1.1 The *Art* of Adhesive Bonding

In a broader sense, the word *art* means any developed action based on knowledge, training, perception, imagination, and intuition as on the initiative to perform it. This description also applies to adhesive bonding, since the development of a safe and high-quality bond also requires similar attributes such as appropriate knowledge, creativity, experience, and innovative strength. It is therefore permissible and appropriate to apply the term *art of adhesive bonding* to the creation of a safe and high-quality adhesive bond ([Figure 1.1](#)).

The classic joining technologies such as screwing, riveting, and welding are used today in numerous applications in industry and trade. However, there are some side effects, such as weakening of the materials involved, uneven stress distribution, and a high probability of corrosion, which the user has to accept. In contrast, adhesive-bonding technology, which can be used to join almost all different engineering materials, offers considerable advantages. Thus, in the early phase of component development, the designer enjoys the design freedom desired through the use of adhesive-bonding technology. And later, after the development of the bonding system has been completed, engineers in the manufacturing plant can easily implement it in existing production processes for individual and series production. The use of adhesives to join materials is characterized by the fact that identical or different substrates are joined over a large area by an organic material (the adhesive), and the resulting system (the

bonded joint) is capable of transferring the acting forces from one substrate to the other. A special feature here is that the bond cannot be detached without destroying it.

1.2 Adhesives

Adhesives are nonmetallic organic materials with sufficient internal strength (cohesion) that are capable of bonding materials through intermolecular interactions occurring at substrate surfaces (adhesion) and transferring forces from one material to another.



Figure 1.1 The creation of safe and high-quality adhesive joints through knowledge, creativity, experience, and innovation.

Two basic requirements must be met for a functioning adhesive, which are accomplished by appropriate adjustment of the chemical composition and physical properties:

- *good adhesion* – provided by sufficient molecular interactions with the material surfaces.

During the bonding process, the adhesive must behave like a liquid, with a relatively low viscosity and the ability to wet the surface of the substrate to establish intermolecular interactions. This allows the molecules of the adhesive to approach the nanometer-scale molecular regions of the substrates.

- *good cohesion* – provided by sufficient molecular interactions within the cured adhesive layer.

In application, the cured adhesive layer must behave like a strong solid with low-molecular flexibility. This is necessary for the transfer of tensile, shear, and peel forces from one substrate to another and to resist environmental influences. Therefore, for good cohesion, the adhesive chemistry must be adjusted to allow molecular interactions within the adhesive layer.

1.3 Adhesive Bonds

An adhesive bond is a two-dimensional connection of similar or dissimilar materials with the help of an organic material that adheres well to the surface of the two substrates to be joined. After the bonding has been prepared and the bonded component is in use, the task of the adhesive bond is to transfer forces from one substrate to the other.

In industry and craft usually, the following materials are used for the creation of an adhesive bond:

- metals,
- plastic materials,
- glasses, and