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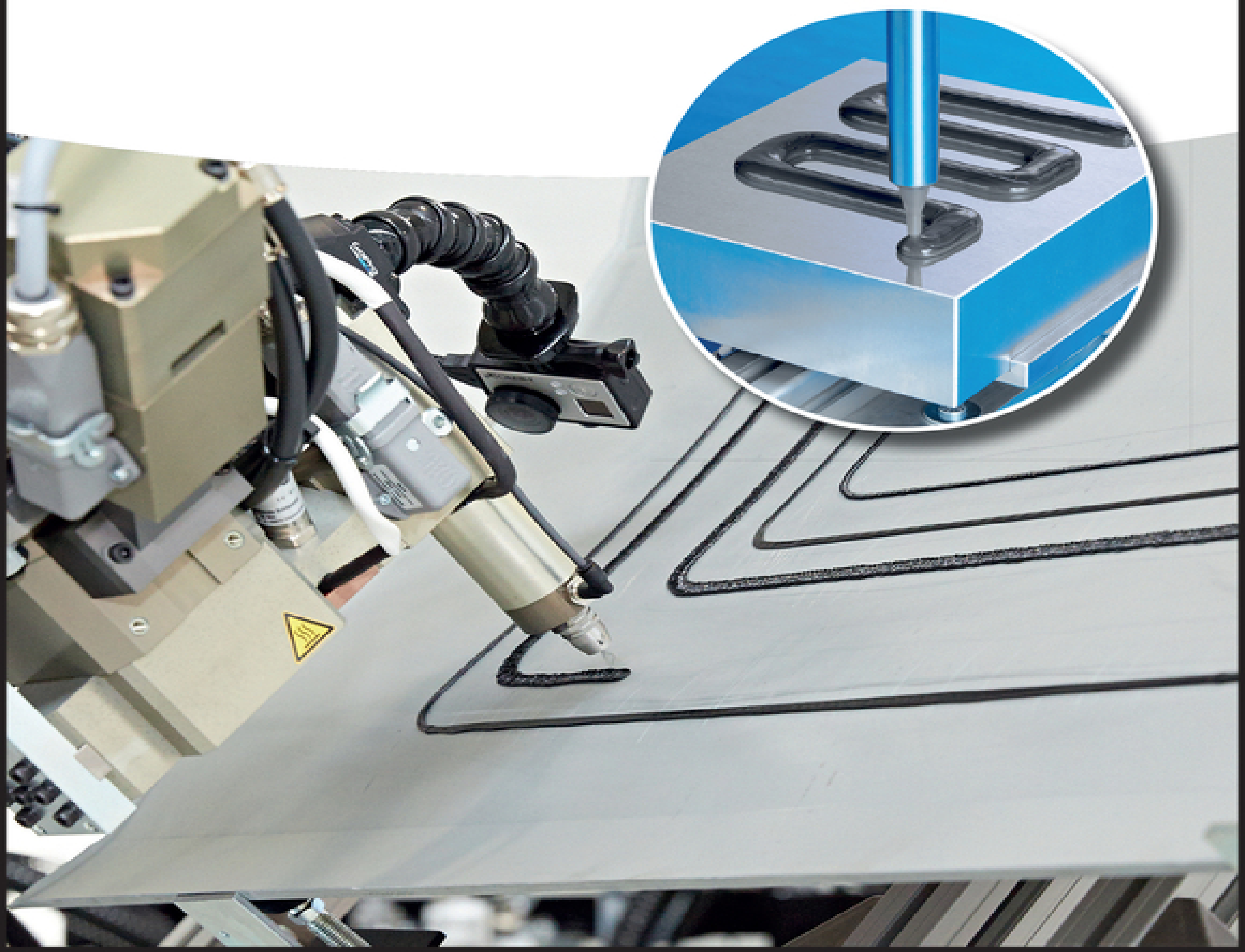
Jürgen Klingen

Adhesive Bonding in Five Steps

Achieving Safe and High-Quality Bonds



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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.

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Dr. Jürgen Klingen

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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 *Dr. Jürgen Klingen*
January 2022

Author Biography

Dr. Jürgen Klingen 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. Klingen 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. Klingen 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